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Young Crossrail Educational Resources

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Developing Educational Resources for Young Crossrail

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by

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Abstract

In this project we designed four programmes for Young Crossrail ambassadors to present to Key Stage 3 students across London. Each programme is designed to link science, technology, engineering, and maths principles to real world examples within the Crossrail infrastructure project via hands-on activities which can be easily adapted to meet the needs of varying class abilities and dynamics.

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Executive Summary

Young Crossrail is currently expanding their portfolio of educational outreach programmes to allow for an increase in the number of school presentations they can deliver to students in the London area through 2019 when the Crossrail transportation project will be completed. Much of their current portfolio teaches students professional development skills like resume writing and interview tips. With their expansion, they are looking to incorporate more engineering activities with direct ties to the Crossrail transportation project that will interest students in engineering.

The goal of this project was to expand the Young Crossrail portfolio by creating four programmes that emphasize engineering within the Crossrail transportation project. Each programme has a hands-on activity where students apply science, technology, engineering, and maths (STEM) principles to solve a real world challenge. To explain and facilitate the presentation of these activities, documents within the programme were created for the students and ambassadors.

Programmes

Our four programmes include the Clockwork Challenge, Station Creation, Structure is Key, and Train Design. Each programme was designed to be taught by a Young Crossrail volunteer ambassador to Key Stage 3 students within a 90 minute time frame suitable for an in school session or after school meeting. They each have students working in teams and incorporate multiple engineering disciplines to model a Crossrail specific concept as a real world challenge for collaborating students to solve.

The programmes were also designed to abide by a set of criteria to facilitate learning objectives. These criteria will ensure that the students have a positive and effective experience, while the learning objectives ensure that the lesson is communicating information strategically to students that can have an impact on their future. These learning objectives are as follows:

- Promoting student interest in STEM fields
- Showing students what engineers do
- Showing students who engineers are

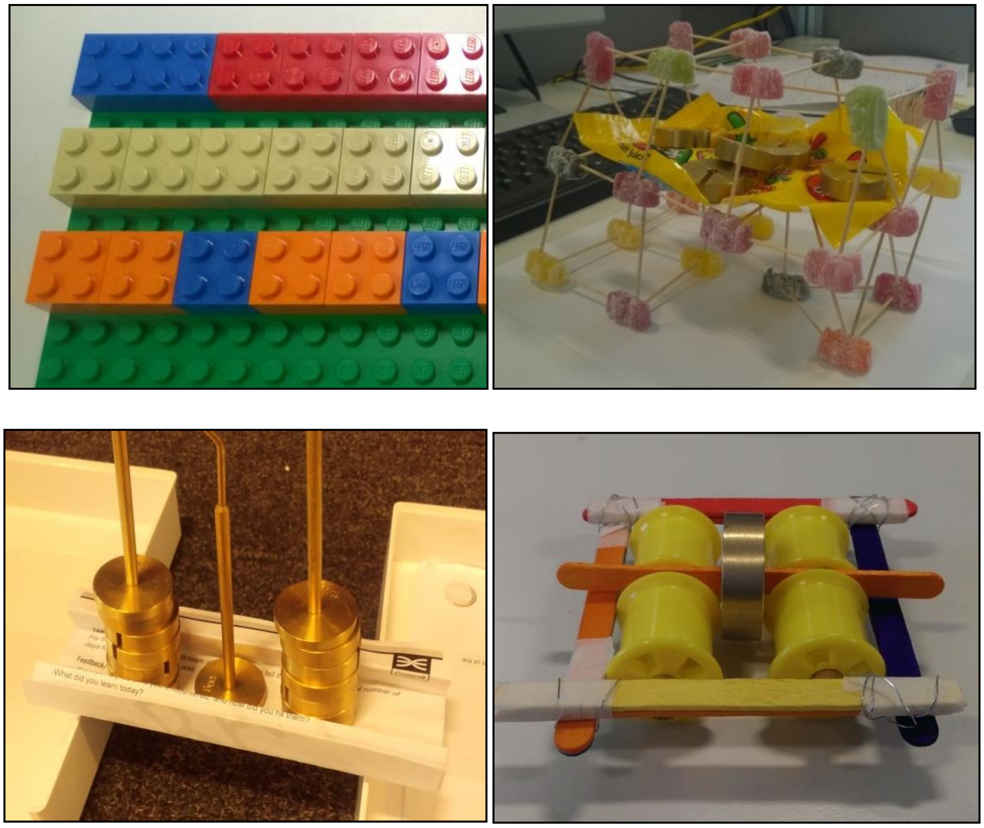

Figure 1: a (top left): One possible Clockwork Challenge Lego Gannt Chart; b (top right): A Station Creation model holding weights; c (bottom left): A successful bridge built during Structure is Key; d (bottom right): One model of a train car from Train Design

The **Clockwork Challenge** asks students to plan the construction of a station using pen, paper, and a Lego Gannt chart to analyse engineering management (Figure 1a). They work in teams of 3-5 to create a schedule including various tasks within the station like masonry or plumbing. Through logical thinking, careful organization, and maths principles students can imitate engineers to work through a construction schedule and even experience the results of real world disruptions, like leaks or worker strikes.

In the **Station Creation** activity, students build a sturdy structure out of toothpicks and jelly babies to imitate the work of architects and civil engineers (Figure 1b). They are assigned different roles within a group of 3-5 students and are asked to design, plan and build a station with encouragement to use their materials as creatively as possible while considering the structural integrity of their product.

The **Structure is Key** activity has students use paper to build two different supporting structures, emphasizing the effects of form on a design’s function (Figure 1c). Working together in teams of 3-4 to meet activity restrictions, students demonstrate civil engineering and materials science principles to evaluate how simple changes in a structure can result in drastic changes to how it holds weight.

In the **Train Design** activity students use crafting materials to build a train car that will run down a rail (Figure 1d). It has students consider railway engineering problems like train car stability and derailing while they work in teams of 2-3 to creatively utilize a broad set of materials and each come up with different solutions to the same challenge.

Each of these activity ideas were based on engineering disciplines of Crossrail that were identified through our research and interactions with stakeholders. Following a brainstorm, test, and revise approach, we experimented with initial ideas, different materials, and various levels of engineering challenges generate our activities. There were failures and successes, and testing was conducted to create fail-proof activity designs. A number of design criteria, such as practicality, adaptability, and variety stemmed from this process, and further guided our designs for complete activities. The activities were also further tested and evaluated by third parties such as the ambassadors, liaisons, and our advisors.

Documents

The greatest challenge in ambassador programs like Young Crossrail is information transfer. In order for our IQP to be successful we had to ensure that all of our programme plans were sufficiently organized and explained so that our liaisons, ambassadors, and students can implement the programmes even though they weren't involved in the design process.

In order to bridge this information transfer gap, we created three documents for each programme that will explain how it should be conducted. These three documents are as follows:

1. Ambassador Presentation
2. Ambassador Guidelines
3. Student Activity Sheet

The Ambassador Presentation contains the bulk of the information about the programme. It is a PowerPoint designed for ambassador use that will lead a user through the flow of the programme and give them guidelines on how to implement every part. This presentation is designed to be easy to use so that any ambassador can present the programme, regardless of their professional and educational background. It also allows for customization: if the ambassador feels comfortable, they can cater the presentation to their own preferences, while making sure to still hit the learning objectives.

The goal of the Ambassador Guide is to make the ambassador comfortable in delivering the programme. It gives them a checklist to prepare and specific instructions to facilitate the activity, highlighting problem areas we discovered while designing and testing. It also includes a set of presentation tips to help ambassadors who would like more assistance on presenting and engaging their student audience.

The Student Activity Sheet is designed to be a concise, easily understandable description of the activity for students to reference while they are planning, building, and testing their activity designs. These sheets also prompt students with discussion topics to keep in mind for the end of the programme.

Terminology

Below is a list of terms that are utilized in this report, provided for a better understanding of the elements and deliverables of the project.

Activity refers to the hands-on component of each programme. Each programme will involve a **Class** of students, divided into **Groups** when necessary.

Programme, refers to the session including a presentation and activity that will be delivered to the students through the Young Crossrail Ambassadors. Each programme has a **Programme Package**, which includes three **Programme Documents:** the **Ambassador Presentation**, the **Ambassador Guide**, and the **Student Activity Sheet.**

Material refers to the physical materials that have been used for each activity, such as lollipop sticks, paper, glue, etc.

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Chapter 1: Introduction

Crossrail is currently Europe's largest construction project and will connect the East and West sides of London via rail. With such a large infrastructure project in the works, Science, Technology, Engineering, and Mathematics (STEM) fields have entered into the spotlight as a large number of people are employed to facilitate the construction of the new rail line in roles ranging from tunnel engineering to logistics and communications management. The Crossrail Project exemplifies and highlights the economic revival occurring in the United Kingdom (UK) right now, especially with regards to the STEM industries. The United Kingdom was ranked third in the world according to a study published in 2004 for its production of highly cited scientific publications (King, 2004). The UK also has a very strong presence in the defence, transportation, and automotive industries with contractors such as BAE Systems controlling about 33% of the Eurofighter Typhoon aircraft's production (Eurofighter, 2014), and Cosworth, along with a multitude of other manufacturers and engineering firms, responsible for a variety of other automobiles and automotive componentry such as engines and gearboxes. This strong presence in the engineering and technology industries has put an increased demand on the current population of STEM professionals and has resulted in a shortage of qualified candidates to fill the void.

A 2006 research effort by the UK Department for Trade and Industry concluded that science, engineering, and technology (SET) degrees as well as employment, unemployment, and inactivity rates of these SET degree holders have remained relatively constant in the United Kingdom over the last ten years (Industry, 2006). Even though the supply and demand for SET degree holders has remained balanced in the past, the massive influx of jobs into the market may pose an issue in the near future, with 42% of employers already reporting concerns with the recruitment of STEM workers in the coming years (Nath & Border, 2013). As a result, there have been numerous studies by representatives from industry and education to determine how to best address the shortage of STEM professionals graduating and the general lack of interest in the STEM disciplines. The National Curriculum of the UK has been redesigned significantly to incorporate more hands-on and engaging approaches to the teaching of the STEM disciplines as a way of inspiring more students to pursue higher level STEM educations, even if they choose not to pursue a career in a STEM field.

Crossrail Ltd., the parent organization responsible for the Crossrail project, has a commitment to "enhance the reputation of public infrastructure projects through community investment and best practice" (Crossrail, 2014). As with many other corporations, Crossrail Ltd. has been using its connection to the STEM disciplines to help inspire the next generation of engineers and candidates for other STEM careers. The massive scale and scope of the Crossrail project offers a variety of unusual challenges, which can be used to inspire and teach the future leaders of the world critical problem-solving and project management skills.

Young Crossrail, Crossrail's education programme, is taking the challenges faced throughout the Crossrail project and adapting them to educate, empower, and inspire students across the UK through the use of presentations and group projects that are facilitated by volunteer ambassadors at career fairs and in classrooms. The programmes of Young Crossrail target students in Key Stages 2, 3, and 4 of the UK National Curriculum, with a predominant focus on Key Stage 3, or 11-14 year old students. The projects and presentations are designed to be age appropriate and adaptable to offer unique or new challenges for different classes of students. The programming offered by Young Crossrail is part of the current trend of ambassador programmes sponsored by corporations to build bridges between subjects and lessons in the classroom, and how these concepts and principles relate to real world projects. The programming also aims to facilitate the development and reinforcement of critical teamwork skills.

One of the issues faced by Young Crossrail is the growing popularity of its ambassador programming, despite the limited number of activities in its portfolio. Presentations and projects can only be modified so many times before they become too difficult to facilitate in a classroom. Also, the programming Young Crossrail employs must be updated as a result of Young Crossrail's desire to keep activities relevant to current activity on the Crossrail project. Due to the programme's heavy reliance on volunteers and the ending of the project's tunnelling phase, it is difficult to develop a large quantity of material to supplement the current portfolio that can satisfy both the need for new ideas to use in classrooms and also the need to keep the lessons and projects relevant to the current work of Crossrail.

The aim of this project is to develop new materials for Young Crossrail ambassadors and teachers in Young Crossrail schools in order to facilitate hands on learning opportunities and engage students in activities that inspire them to pursue further education in the STEM disciplines. The team will focus on developing materials targeted towards Key Stage 3 that can be simplified, supplemented, or modified to provide unique challenges for students in Key Stages 2 and 4 as well. Extensive background research has been conducted to determine how to best design and implement projects and presentations for a classroom or scholastic setting. The team will use this information to create a portfolio supplement containing a variety of activities that may also be published on the Young Crossrail website.

Chapter 2: Background Research

Young Crossrail has a portfolio of activities that inspire young people to study STEM disciplines and prepare them for the professional world. The organization is currently seeking to expand its portfolio with activities that promote engineering and provide a basic foundation for students to make informed decisions regarding the pursuit of engineering after graduation. These activities will build off of what students already know about the STEM disciplines and promote the STEM fields in a positive light. The activities will follow the current style of project and lesson presentation that Young Crossrail's current ambassador programme employs, where the structure and assessment of the program's portfolio will self-sustain and evolve with the changing classroom environment in order to fulfill the goals of Young Crossrail.

In order to facilitate the development of these activities, the following areas of background research are needed:

2.1 Young Crossrail

2.2 Audience Recognition

2.3 Criteria for Project Success

2.4 Ambassador Programs

2.5 Successful Education Projects and Materials

2.6 Project Accountability

The background research provides a fundamental understanding of how students can be taught engineering so that it is relatable, interesting, and effective. Combined with current research on ambassador programmes and effective STEM outreach activities, this will help us develop, implement, and assess a series of activities that presents information and hands-on projects to the students.

2.1 Young Crossrail

The following section contains information about the sponsor of this project, Young Crossrail, and their educational outreach programming. Starting with a description of the sponsor, it will cover the key aims and current state of their programme and its implementation, including organization and limitations. Furthermore, the section will discuss our project group's development of a programme supplement.

2.1.1 Who is Young Crossrail?

Young Crossrail is a branch of Crossrail Ltd., which oversees the construction of the Crossrail project involving the construction of new rail lines through the City of London, including nine new stations and 119 kilometers of track with 21 kilometers of new twin-bore rail tunnels upon completion. Once open in 2019, Crossrail will greatly reduce journey times, easing congestion and improving connections between London's main employment centres. By carrying an estimated 200 million people each year, it is projected to increase London's rail-based transport network capacity by 10 percent. Crossrail is expected to add an estimated £42 billion ($70 billion) to the British economy supporting regeneration and a "legacy of economic sustainability" in the UK (Crossrail, 2014).

The Crossrail transportation project manifests many STEM disciplines in its construction and implementation, with the boring and constructing of tunnels being the main demonstrations of STEM fields during the early phases of the project. However, as basic construction ends and Crossrail becomes integrated into the city infrastructure, other engineering disciplines will become more dominant. Young Crossrail hopes to illustrate the engineering disciplines involved in the Crossrail project to students who are directly engaged with and affected by the project (Hillier, 2014a, 2014b).

2.1.2 What does Young Crossrail do?

Young Crossrail is an ambassador "engagement programme" utilizing an informal learning environment to promote STEM to students located in the vicinity of the Crossrail routes (Hillier, 2014c). The programme involves volunteer ambassadors who lead activities and events to spark interest and promote career paths in STEM fields, in addition to preparing students for the professional world (Hillier, 2014c). Young Crossrail aims to share the "plans and progress of their groundbreaking transport scheme," under the philosophy that engineering plays a key role in a broad range of industries (Crossrail, 2014).

2.1.2.1 The Ambassador Programme

Young Crossrail uses a network of 189 ambassadors from various backgrounds including Engineering, Systems Integration, Human Resources and Management to implement activities and events in six partner schools (L. Hillier, personal communication, March 20, 2014). These ambassadors promote the STEM fields and engage students by hosting hands-on activity sessions that give young students basic engineering and shadowing opportunities. Ambassadors also conduct wider spread events such as school-wide presentations, career-focused fairs, mock interviews, and STEM conventions (Hillier, 2014b).

Young Crossrail supplies its ambassadors with activity ideas and templates to help them plan and execute the educational sessions. Since ambassadors work directly with students and provide support and guidance to effectively conduct these educational programmes, ambassador input and feedback is helpful in furthering lesson plans (Hillier, 2014b). One basic tool provided by Young Crossrail is a presentation template for the ambassadors to organize their lectures into different sections, including the following:

- Introduction
- Personal job details
- Work environment discussion
- STEM they practice
- Career advice

(Hillier, 2014a)

With this presentation, ambassadors are given a plan to engage their students and introduce the work and industry they are involved in. They provide their own photographs and details from the workplace, share their experiences with colleagues, tell students which courses they took in school, and which career paths are available in different STEM disciplines ("My Career Journey YC Template," 2014).

2.1.2.2 Existing Portfolio of Activities

The class activities hosted by the ambassadors provide knowledge and understanding while engaging students with hands-on activities and introducing scientific concepts with familiar examples. Activities that have already been implemented exhibited basic engineering themes that connected back to the Crossrail project and the many engineering disciplines it envelops.

For example, a “Crane Activity,” which was actually developed by an ambassador from an engineering background, was implemented to demonstrate the scientific concepts behind a crane that could be commonly observed at a construction site. The activity involves a list of materials, a demonstration conducted by the ambassador(s), and an information sheet for the students. The information sheet familiarizes students with an object, a crane, and explains the basic physical concepts associated with that object. The class is then given a task of constructing their own crane with the provided materials to make it perform a basic task (Hillier, 2014a).

Another activity implemented was the well-known “Spaghetti Challenge,” where students are required to build structures using marshmallows and raw spaghetti. A Crossrail variation adds a trading element to the activity, where students are allowed to trade ingredients to achieve better results.

Another programme implemented at “Young Crossrail enterprise challenge day” involved teams of three to five primary school children learning to negotiate across groups for construction materials in the process of building prototype bridges that were judged based on overall strength and aesthetics. Young Crossrail’s manager, our project liaison, is quoted saying “Building bridges is an inspirational experience for everyone. We’re always so impressed by the children’s creativity, resourcefulness and natural team spirit” ("Young Crossrail Building Bridges," 2013).

The current portfolio of activities are centered around civil engineering, but as Crossrail finishes its construction and moves on to infrastructure and prepares to activate its routes, Young Crossrail hopes to expand their portfolio to new, relevant activities, including mechanical, electrical and systems integration engineering with further focus on physics, environmental science, geography and geology (Hillier, 2014c).

2.1.2.3 The Website Component

The Young Crossrail website is an effort to extend the current portfolio beyond the classroom so the activities can be used by members of the community outside of the six target schools. In addition to the expansion of its existing physical portfolio, Young Crossrail hopes to distribute a key set of Crossrail specific materials for educators and students through this website.

Currently, the website contains a number of examples and suggestions for students which utilize route maps, facts and videos regarding the construction progress, as well as mapping tools to demonstrate the progress of tunneling machines. In addition, the Career Pathways section provides a set of instructions and examples that older students considering more advanced career paths may find useful. Through this webpage, Young Crossrail highly emphasizes apprenticeships with contractors, opportunities for graduate engineers, and the Tunneling and Underground Construction Academy (TUCA) for individuals who are interested in a career with railway construction and infrastructure (Crossrail, 2014).

While the website has some useful student resources, it lacks any educational resources for download, as well as details regarding the Young Crossrail programme and how to get involved. There is no structured set of materials or guides to help students learn, but there is a set of links to other STEM organizations and engineering organizations. These other sites are linked to provide guides to expanding STEM education through teacher resources, STEM clubs, and more.

2.1.3 Why does Young Crossrail host its outreach program?

Crossrail hosts this programme in order to encourage students to pursue STEM fields, influence subject exam choices, and to ultimately shape career paths (Hillier, 2014c) because there will be an increased demand for STEM professionals in the upcoming decades. EngineeringUK, in its 2013 annual report, stressed the need for the United Kingdom to double its output of college level engineers by 2020 (Bosworth, Lyonette, Bayliss, & Fathers, 2013). England is one of the key components in supplying these STEM professionals for the entirety of the UK, helping keep the STEM supply and demand balanced (Bosworth et al., 2013). In addition, 65 percent of the UK's exports are from high tech firms, making its overall economy depend greatly on STEM professions (EngineeringUK, 2014).

While government agencies, legislation, and other traditional methods are addressing the problem, The Crossrail project itself exhibits STEM as it progresses from planning to construction through 2018. As Europe's largest infrastructure project, Crossrail has more than 40 construction sites sprawled across England (Ltd, 2014). Various engineers from different disciplines are already at work. The Crossrail project is a highly visible example of STEM concepts that can be highlighted in classroom settings to promote STEM interest in young students.

2.1.4 How do we fit into this program?

Young Crossrail hopes to develop Crossrail specific resources that ambassadors can utilize, through presentations and assemblies to classrooms or school clubs. Additionally, these resources should focus on specific STEM fields so that they augment much of Young Crossrail's current material that is about professional development.

Developed activities will teach students about the following engineering disciplines: mechanical engineering, electrical engineering, and systems engineering. The activities will directly relate to developments in the railway construction. For example, current projects involve civil engineering and are designed to relate to real world tunneling. But as tunneling ends, Crossrail liaisons Kate Myers and Lauren Hillier said they would like the activities to be updated and include different challenges relevant to those Crossrail will be facing, such as "how everything will work together" (L. Hillier, personal communication, March 20,2014).

2.2 Audience Recognition

Audience recognition is a fundamental first step in every information transfer procedure. It is important to cater a presentation to the needs and understandings of those receiving the information, in this case the students. In order to optimize this project, a basic understanding of what students know about engineering and how they learn is necessary.

2.2.1 What do students know about engineering subjects?

To tailor activities to increase interest and inspire commitment to the STEM fields, the United Kingdom current curriculum needs to be closely evaluated to see what students already know in these subject areas. This UK education system will tell an activity designer what the students have been exposed to in a formal education setting, thereby establishing a basis for this project to complement.

The National Curriculum mandates minimum standards for public school curriculum but only dictates when certain benchmarks should be completed so that individual schools are left to decide which grade level classrooms should introduce and follow up with continued approaches for each benchmark. Topics categorized by Key Stages and relating to STEM fields useful to this project are found in Appendix A (Education, 2013).

The National Curriculum was revised in 2000 to cope with STEM employment changes. The revisions included making mathematics and science mandatory for years 10-11 during the secondary stage of a typical public education in England. These subjects were not required previously at this grade level, which is evidence that there has been a change in attitudes towards the STEM disciplines (Organization, 2007). Additionally, in 2013 mandatory attendance in schools was raised from age 16 to 17 and the age will be further increased to 18 in 2015 (Nath & Border, 2013).

2.2.2 What do students know about engineers?

In research about the sociology of STEM education, several studies have shown that students lack the ability to differentiate between STEM disciplines and believe misconceptions brought on by social influences. These are target areas that provide specific design goals and considerations within our project. Our success will be partially determined by how well we can integrate perspectives into the students' current views of the STEM fields.

Engineering Impressions

A 2005 study of over 500 first through fifth grade students in the Midwestern United States asked them to identify examples of work an engineer would do. The top 4 choices for engineering work, in order from highest to lowest were: repair cars, install wiring, operate machines, and construct buildings. When prompted about design being an engineering discipline, less than 35% of students responded (C. M. Cunningham, Lachapelle, & Lindgren-Streicher, 2005).

As students get older this trend continues. In a separate study of 6th graders, 14 of the 20 students involved in the interview understood that engineers were involved in a process that resulted in building things. They exhibited a more thorough understanding of this process that generally fit into the engineering scheme exhibited below in Figure 2, however they didn't explicitly mention more than two of these stages: planning and building (Karatas, Micklos, & Bodner, 2011).

Figure 2: Engineering Process

Half of these 20 students understood that engineers do more than building, like fixing, but only 25% understood that they design things and only 25% suggested that they consider specifics about planning the project, like cost or how big it is (Karatas et al., 2011). In addition, they commonly confused architects', construction workers', mechanics', carpenters', and scientists' professional duties with those of an engineer (Karatas et al., 2011).

One of the more interesting facets of this sixth grade study was that the students' impressions of engineering were very flexible and even changed throughout the study; they didn't know what to think. The study suggests using this information, these "preconceptions," to base a curriculum on. “Analysis of the data suggested that the students’ concepts of engineers and engineering were fragile, or unstable, and likely to change within the time frame of the interview” (Karatas et al., 2011).

These two studies clearly illustrate three conclusions:

1. Students do not understand how engineering is different from other professions.
2. Students do not understand that design is a part of the engineering process.
3. By 6th grade, students are able to understand that there is a process to engineering.

Technology Impressions

In the same study of first through fifth graders, they were asked to identify examples of technology. They were abundantly aware that things involving electricity are examples of technology, for example television, cell phones, power lines, and the subway. This presents a slight confusion in that 34% of the students identified lightning as a type of technology. Through verbal responses students associated technology with certain actions they do to use the items, like plugging them in or charging them (C. M. Cunningham et al., 2005). This shows that students base their understanding of technology on their everyday lives, but that they have no conceptual understanding of what technology is or what it does for mankind.

2.2.3 How do students learn effectively?

STEM curricula have gravitated toward lectures and rapid information transfer in order to cope with an ever increasing influx of information. As this happens, it has been shown that students understand less of the actual goals of STEM fields and are subjected to rigorous memorization and rule following, which drastically decreases interest in the STEM fields (van Driel, Beijaard, & Verloop, 2001). This decrease in STEM participation is what the Young Crossrail programme is striving to reverse, and it is choosing to do so by implementing a curriculum that differs from the traditional classroom lecture experience.

When it comes to inspiring and teaching children about STEM, there tends to be one common theme: teach it interactively. “The brain constantly seeks to connect parts to wholes and individuals learn by connecting something new to something they already understand. . . It responds far more effectively and efficiently to something that carries deep and personal meaning, something that is life shaping, relevant, important, or taps into emotions,” (Tomlinson, 1999).

Many teachers and administrators have recognized the need to relate the lessons in the STEM fields to real world examples, such as places and products the students see and use every day. Companies such as BAE Systems, Ford, IBM, and Dell have recognized this need and have developed systems in the UK to fulfill this need through ambassador programs, in which representatives, often engineers, from the companies spending between two and six days per year in local school (Wilks, 2002). At the schools, these representatives assist teachers in developing lesson plans and interactive projects to be used either during the lessons are as a part of after-school programming (Wilks, 2002). Corporations, such as BAE Systems, have also developed new methods of teaching STEM, and inspiring youth to explore engineering further. BAE has created a theatrical approach to the stereotypically art free world of engineering by developing a roadshow of two female and one male actor to introduce the audience to the type of projects the firm encounters. A second phase to the visit involves an engineering workshop aimed at involving students "in teamwork, creativity, and problem-solving." After the presentation, BAE Systems continues to assist educators in the development of projects and lessons inspired by the visit. BAE's roadshow approach was developed in 2007 and aimed to reach ten thousand students during the same year (J. Cunningham, 2007).

Because STEM is a representation of "a symbiotic relationship among the four interwoven fields," (Basham & Marino, 2013) it must be taught in a manner that doesn't isolate any one discipline from the acronym. Many of the strategies and lessons learned through STEM, and specifically the Engineering aspect, can be adapted for use in other fields.

For the students, working in groups to tackle challenges as simple as bridge building with newspaper and tower building with spaghetti pasta, tape, and a marshmallow can force them to innovate, collaborate and adapt to different experiences, all part of engineering design and prototyping. In addition, the facilitators learn from students. They learn lessons regarding group dynamics, learning styles, and even design ideas through observing the young, creative minds at work.

2.3 Keys to Project Success

Beyond purely teaching students about STEM fields, we must consider our social impact. After all, Young Crossrail operates in informal learning environments where students learn through activities and out of personal interest without any pressures imposed by a learning environment (Bell, Lewenstein, Shouse, & Feder, 2009). We have already covered what students know about the STEM fields from classroom learning, but what they think about engineering as a discipline is equally important. It is found that what little students know about engineering is often exaggerated or completely false, which brings us to our first social impact: correcting misconceptions. Second, students come in all shapes and sizes; our programme must reach all students regardless of their socioeconomic standing, cultural background, and individual smarts. Last, returning to our primary goal of inspiring interest toward the STEM fields, areas that are considered "fun" by young students must be explored.

2.3.1 Overcome misconceptions

In addition to building on an educational foundation already established, we are also going to be working to amend first impressions that students, teachers, administrators, and other members of the general community have had about the STEM fields that may or may not be correct (J. Cunningham, 2007). Engineers, educators, and technological corporations all have a stake in portraying an accurate and positive impression of engineering. By dedicating time in

Young Crossrail activities to taking away misconceptions existing in the STEM fields, Crossrail will be able to contribute to its community long term by:

- Sustaining UK capacity for technological innovation
    - Understanding the nature of STEM work environments educates policy makers and the public to STEM contributions in economic development and quality of life
- Increasing the pipeline of youth into STEM fields
- Removing misconceptions of the people in STEM fields that often discourage or intimidate youth from committing to the STEM fields.
- Improving literacy in math and science
- Improving competency in math and science, which is crucial to the technology-dependent society found today.

(Messages, 2008)

Identifying Misconceptions

Research suggests that people form their opinions about STEM prior to being formally educated about it. Students in particular, get impressions from films, textbooks, TV programmes, relatives, and parents before they learn about STEM in a classroom setting. This would not be a problem if everyone understood the STEM fields, but research also shows that, a "vast majority of members of society" believe widespread myths about the STEM fields, myths which then spread to children and take away from the effectiveness of STEM outreach (Karatas et al., 2011).

For example, students believe that science facts are purely objective and don't rely on human interpretation or imagination (Karatas et al., 2011). When evaluating potential career opportunities, it would be easy for a student to see STEM fields as uncreative and pass over them quickly either because they find this boring or they feel they are too creative for such a field.

People also believe that engineering work is mostly performed on computers and requires minimal collaboration and contact with other people (Fenichel & Schweingruber, 2010). This could be a discouragement to students who like to be social or who think their leadership skills will not be valued properly. Projects are one of the most common, effective engineering practices and can demonstrate to students the necessity of engineering social skills.

In addition there is a common perception that science is a subject reserved only for the best students (Nath & Border, 2013) or that engineers are "smart" (Karatas et al., 2011).

A 2013 survey revealed that there has been an increase in positive perceptions of engineering across all age groups and that parents are more likely to recommend STEM fields to more able students than ever before (EngineeringUK, 2014). While STEM fields do attract very intelligent people, the image that engineers have to be smart is damaging to the general STEM populace because there are a great variety of STEM professions that require aptitude in different levels and subject areas. As a result, the typical demonstrations which depict STEM fields as cutting edge and complicated can hurt the numbers of youth pursuing STEM fields (Messages, 2008). This misconception could be amended by project work that encourages students to work diligently, and by showing them that grand displays of innovation can be created from a good deal of diligence and a little bit of creativity.

Addressing Misconceptions

Now that misconceptions have been identified approaches to address misconceptions can be proposed. One way to do this is to present engineering by explaining its goals. Results of engineering are judged on how useful they are and its objective is the application of science for human benefit (Lynd, 1998). To help the youth understand engineering in an informal learning environment engineers should be characterized as those who:

- improve the quality of life
- design and build
- are necessary to society
- have answers. If not, they are ones who can find answers
- make things happen or make things better
- link creativity and practicality

(Messages, 2008)

As a general approach to redefining the way that the public views STEM fields, educators could take the approach of promoting engineering with emphasis on engineers making a difference in the world and less emphasis on describing associated professions with skills required and personal benefits of STEM involvement (Messages, 2008). For example, medical doctors should take on the image of those who cure disease and work against human suffering instead of the process of becoming a medical doctor. With this approach, STEM fields are promoted in a way that appeals to a student's desire to make a difference rather than an appeal to show how competent they are as a student (Fenichel & Schweingruber, 2010).

2.3.2 Reach a variety of people

The audience of these activities will vary based on their abilities, socioeconomic status, cultural background and intelligence level. In some places, the classrooms will be more cohesive but it's likely that each learning environment will be a mixture of all of these qualities. Our programme must keep in mind these different backgrounds; below is a discussion of successful methods in each area.

With the recent trend of integration in the classrooms, teachers are presented with the challenge of teaching lessons that can simultaneously reach and challenge the most talented students, as well as not overwhelm those students with disabilities. Many of these students have the potential to effectively contribute to the STEM-related industries, but because of “this disengagement . . . students with disabilities rarely enter the STEM workforce” (Basham & Marino, 2013).

Another aspect of diversity is based on the socioeconomic status of the students, and often leads to an academic performance deficit from the lower class and impoverished pupils. The ones who don’t have access to the same educational materials because of socioeconomic status are often the ones who need the higher quality education and support networks, including mentors and teachers driven to help these youth to excel.

In 1975, the Massachusetts Institute of Technology (MIT) began to address these issues and make a change by launching their Minority Introduction to Engineering and Science, or MITES, programme (Shemkus, 2013). MIT’s MITES programme focuses on inspiring minority and disadvantaged students to learn more about the STEM disciplines. Most of the instructors for the programme are MIT alumni or graduate students, rather than MIT professors (Shemkus, 2013). Another organization that takes a different approach to reaching out to underprivileged youth is Luk Inc., which is a national organization with an office based out of Fitchburg, Massachusetts. Some of the services provided include street outreach, vocational/educational support, and mentorship programs, all of which are aimed at helping to empower and guide homeless and impoverished youth to be able to learn the skills required to help lift them out of poverty and homelessness and change their own lives. These programmes bring the classroom and support networks, rather than bringing the students to the classrooms like the MITES program. The mentorship and support networks are critical to the success the educational programs. Professor Mitra discovered this in his Kalikuppam Experiment, and refers to it as the “Grandmother Approach” to mentoring. By simply having someone to oversee and encourage studying and educational growth in a positive manner, just like a grandmother, academic performance levels can increase significantly (Mitra & Dangwal, 2010; TED, 2010).

Another element to consider in teaching STEM is the intelligence of the audience. “Intelligence is multifaceted, not a single thing . . . is fluid, not fixed. . . [and] neurons grow and develop when they are used actively; they atrophy when they are not used,” (Tomlinson, 1999). As a result, teachers and facilitators must keep in mind that everyone learns differently and “all students must continue vigorous, new learning, or they risk losing brain power,” (Tomlinson, 1999).

By keeping in mind the level of diversity in the modern classroom, a programme designer can more effectively develop activities that provide challenges of appropriate difficulty that can engage all students, allowing for an activity to make a stronger impact on a larger range of students.

2.3.3 Activities should be interesting and fun

One challenge we will have to face is making our activities appeal to young students; in essence the entire purpose of this programme is to show students that STEM fields can be interesting. This is comprised of two parts: 1. that they can relate to the information, and 2. that they find the information captivating.

"Science, Technology, and Society (STS)" is the study of a broad array of topics involving sociology and science research that began in the 1980s. Here we can make use of their studies on sociology applied to STEM education. One method STS finds successful is to show students practical applications: how the STEM fields relate specifically to work, citizenship, leisure and survival (Mansour, 2009). With the Crossrail project in construction throughout London, it will be easy to show students how STEM fields relate to work; they can walk home and see examples. The other three categories will be more difficult. Two questions we will have to pose in curriculum development are: How do the STEM fields contribute to the community as a whole? How do the STEM fields make life easier and better for individuals in the community?

2.4 Ambassador Programmes

Ambassador programmes generally contain three main groups of people: the information developers, the teachers, and the information receivers. With respect to our project, activity and programme designers will develop the lesson plans, the ambassadors will teach the information, and students primarily in Key Stage 3 will be receiving the information (Figure 3).

Figure 3: Flow of Ambassador Programmes

One particular problem area with this system is information transfer: how to prepare the ambassadors to teach the students. Designers must pay extensive attention to how this problem has been approached in the past in order to optimize the process, taking into consideration that the ambassador programme must sustain itself and that Young Crossrail currently has little formal training for ambassadors. One way to do this is to create a set of guidelines for ambassadors to reference in preparation for the lesson. Most of the ambassadors are practicing engineers who will have practical STEM experience, but very little teaching experience. An additional component of our project might require the creation of materials to be presented by teachers to classrooms after the ambassador has planted a STEM seed.

2.4.1 How are current ambassador programmes structured?

Examples of current ambassador based programmes include Project Lead the Way (PLTW), a programme developed at the national level in the US, which enhances the current in-school curriculum. Project Lead the Way focuses on promoting STEM fields through a variety of activities delivered by teachers that complement in school curricular requirements regarding STEM. The programmes range in length from 1.5 months (for middle school students) to one full year (for high school students) (Cyr, 2014).

PLTW hosts extensive training workshops for teachers during the summer where they undergo a two-week long training session to prepare to teach students throughout the next year. Because they are teachers, however, they need less content on education and more information on the subject material i.e. how to run a CAD software programme. With Young Crossrail, this training should focus more on the former area, providing engineers with information on how to educate students (Cyr, 2014).

In order to maintain this teacher network there are "master teachers" who are more involved and educated in the programme and can answer questions other teachers have. Additionally, teachers have a blog online where they can communicate amongst themselves when they find ideas that are effective or have other questions (Cyr, 2014).

While we are not able to have an extensive training programme like this, we have many other options to create a set of guidelines for Young Crossrail ambassadors to learn from. In an interview with Martha Cyr (director of the Massachusetts hub for PLTW through WPI), she mentioned a few concerns we will have in working with engineers and teachers, as described below.

Teachers and Engineers as an audience:

While teachers have years of experience in a normal classroom setting, these hands-on projects are often quite a different experience for them. "Teachers are often scared because projects don't have an end. You are supposed to learn through failure and retrying," (Cyr, 2014). Deviating from the normal classroom structure can make them uncomfortable, which is something our ambassador model will strive to correct.

Engineers, on the other hand, have more experience with actual projects than with teaching them; they are more prone to "dumping information" on an audience. The guidelines given to engineers should emphasize touching, learning and doing to help them engage their audience (Cyr, 2014).

Ambassadors in general:

The key to success with ambassador guidelines is comfort. They must feel comfortable replicating the described process after we leave (Cyr, 2014). Within the lesson, we should focus primarily on the things teachers and ambassadors will find challenging. One method is to videotape ourselves presenting a lesson as a clear model of how it could be effective. After the initial model has been made, Cyr suggests that the ambassadors should be given time to implement the lesson and that we should collect feedback about the effectiveness of both the lesson content and guidelines (Cyr, 2014).

2.4.2 What type of educational documents do these ambassador programmes have?

While PLTW does not release its projects to anyone other than trained teaching professionals, there are many websites that gather information about STEM educational programs. One such site is Teach Engineer, a searchable database of units, projects, and lessons for students of all ages.

In a curricular unit entitled "Creative Engineering Design," students develop a product by following a specific engineering design pathway, shown below in Figure 4.

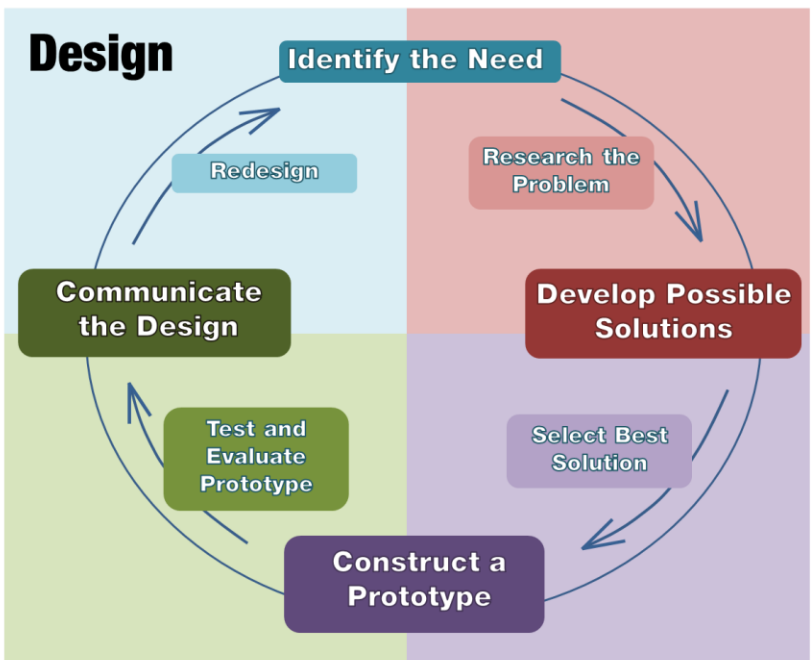


Figure 4: Engineering Design Process

This particular schematic is very broad and can be applied to many engineering projects. Some examples would include amusement park rides, house development, or solar and water technologies ("Curricular Unit: Creative Engineering Design," 2014). In the development of our lesson plan, we can use this schematic as a template to implement our own project.

To branch off of this schematic (Figure 4), we can create a project that poses the students with a problem and asks them to find a solution, giving a range of materials and providing them with the engineering process but refraining from giving them specifics on what the solution should look like or should be modeled after. Teach Engineering has an example of a project like this, entitled "Service-Based Engineering Design Projects." Its practicality extends beyond the stand-alone engineering design process because it shows students what a practicing engineer will be doing: solving specific problems ("Curricular Unit: Service-Based Engineering Design Projects," 2014). To increase the difficulty of the project for older age groups, this challenge could impose restrictions, for example, a cost restriction, or the inability to access certain materials. To address one of our primary concerns, time, this full project normally takes 13 weeks and would have to be scaled down drastically to complete in one after-school session.

The project itself will focus on specific areas within Crossrail. Director Cyr, in the same interview as mentioned before, suggested a general protocol to follow during project development:

1. Break the Crossrail project into subsystems
2. Create real-life solutions to subsystems
3. Model to what kids use and relate back to Crossrail project

Breaking the Crossrail project into subsystems will allow us to analyze the large system on a smaller scale, looking at specific problems and solutions. From there we can isolate specific lesson content to highlight and clearly show students how it relates to a real-life problem. Finally, by modeling this content to something kids are familiar with, we will be able to create a link between Crossrail and the students they will understand.

For example, at a Crossrail construction site one problem can be tunneling. By focusing on this problem, we are able to isolate solutions in practice, i.e. the technology Crossrail employs to drill a safe, usable tunnel. This can be related back to a child's personal life, where possibly they have a pet hamster that runs through a network of tunnels at home for fun (Cyr, 2014). Thus, we have created a link between something the student cares about (their pet hamster) and the real-life engineering situation (tunneling).

2.5 Educational Projects and Resources

In order to gain insight into how documents for activities are structured, what kind of information should be included, and how the general programme should be structured. The project group researched a number of existing educational resources and projects relating to activity-based STEM education. Examples of content and structure exhibited in these resources allowed us to construct an effective methodology to create our own documents. This allowed the project team to identify the key elements used to create educational resources, how content organization influenced information portrayal, and possible limitations in designing a programme.

2.5.1 Engineering Education Project in Worcester

"Engineering Lessons for a Sixth Grade Classroom" is a Worcester IQP completed in 2004 that created a set of engineering education materials and a lesson plan to implement activities. The project allows us to see the methodological approaches taken by the project group to implement their subject-specific materials. Additionally, the general lesson plan provides insight into how the subject material should be chosen and implemented into activities (Ward, Fichter, Bradley, Bishop, & Rencis, 2004).

The project began with an overview of what activities, events, and academic programmes are held throughout the year and in the summer in the targeted Worcester public schools. This approach allowed the group to see what was already being implemented and identify a basis to work on, as well as potential problems and limitations. This method will be utilized by our project group, as we identify and evaluate the current Crossrail Ambassador Programme and use it as a basis for the activities we construct.

The members of the Worcester IQP project team developed a lesson plan to strategically implement their project. This lesson plan included may critical elements that defined the scope of the project. Among the many elements present, we concluded that the following elements were critical to the overall structure of their project, and could be extensively replicated in the structure of our programmes.

Table 1: Lesson Plan Critical Elements

An Introductory Lesson	Introduce engineering in general. Allow Students to understand the different engineering disciplines that are present in the world using real life examples of engineering applied to solving issues.
Allow Identification	Allow students to apply what they learnt about engineering by allowing them to relate examples, graphics, and descriptions with engineering disciplines.
Rubrics	Rubrics, guidelines and standards that evaluated the effectiveness of the material, based on project team and teacher evaluations.
Deriving an engineering discipline from a familiar concept or object.	Begin with introducing a familiar object or application that students can easily identify with. Identify the scientific concepts that are involved in that example. Connect the scientific concepts with an Engineering discipline and how engineers use their scientific knowledge to implement such real life applications. Examples include -Roller coasters and their kinematic physics principles linked to Mechanical Engineering -Functions of the Human Body and anatomy, biology principles, linked to Biomedical Engineering. Young Crossrail will require activities which tailor towards engineering disciplines involved in the Crossrail Project.

2.5.2 Educational Resource Project in London

A London IQP proposal, “Development of Key Stages 2 and 3 Teacher Resources in the Areas of Space and Flight for the Science Museum” involved the creation of teaching resources including activities, experiments, and interactive media that engaged students in Space and Flight areas exhibited at the Science Museum (Zoll et al., 2008).

This science museum project provided standards of how educational documents should be prepared, structured, and distributed. These activities were focused on a single discipline, tailored to a specific engineering problem or concept. This allowed the project group to provide specific templates, instructions, and manuals for teachers. Young Crossrail currently requires materials that relate to engineering disciplines utilized in the Crossrail Project, so this strategy of approaching the activities with a theme could be applied to our project.

The science museum project paid close attention to feedback from teachers in order to recognize their needs and any limitations they had discovered. One of these major limitations is the time constraints of the teachers utilizing the material. This includes not only the time presenting the material to students, but also how much time is spent in preparing the classes and sessions for students. The preferred materials were those that reduced time constraints, including easily printable material and materials that were designed to “invoke discussion in the classroom”. Thus, the project focused on creating “ready-made ideas with clear educational objectives” (Zoll et al., 2008). Our project should also focus on this time limitation, with the conducted activity sessions being an hour to an hour and thirty minutes long. Additionally, our ambassadors are volunteers and have limited time to prepare for these sessions. Our educational documents should be clear, easy to deliver, and ready to implement with full instructions of the activities and detailed manuals for the ambassadors to assist the sessions.

2.5.3 London Science Museum Resources

The “Educators” section of the London Science Museum website has classroom resources organized by different age groups and subject areas within science. A range of disciplines are covered, including Environmental Science, Biology, Chemistry, Physics, Energy, etc. Each resource has an activity sheet with instructions for the activity, and a manual for activities that should be conducted under the supervision of instructors and teachers ("The Science Museum: Classroom Resources," 2014).

Activities categorized for students of Key Stage 3 are mostly intuitive and discussion based, focusing on demonstrations and issues in science development we face, and providing help for teachers to involve students in discussing the educational documents delivered.

Three main resources provided significant assistance for more in-depth discussion and student engagement strategies. These would be an excellent basis for the manuals that we plan to construct for ambassadors to use in activity sessions. Ambassadors will be able to actively engage students in activities and discussions with these structured discussion templates and strategies in mind.

The first resource, named “Discussion Formats”, discussed the effectiveness and purpose of different methods of discussion organization. The formats, provided through video instructions, provide different discussion formats that provide useful guides for different discussions and subject matter.

Table 2: Discussion Formats

Market Place	Divide class into research groups, and provide sub-topic or viewpoint information. Group members gather information and Groups are dispersed into mixed groups again, forming an “Expert Conference” and share their “Expert” information. Useful for disseminating a large amount of information and acquiring multiple different angles and points of view on the issue.
Role Play	Students act out a scenario about a topic in character, as individuals involved in an actual project, situation etc. Borrow TV show formats familiar to the kids. Effective when students share a common view on topic. Promotes wider thinking of the issue
Socratic Seminar	Whole group is given information on the topic, in the form of text, short film, or other subject stimulus. Class is divided into two groups, forming an inner discussion circle and is asked to discuss based on instructor’s prompts. The other listens to the inner circle. After some time, switch the circle roles. Emphasizes the role of listening, useful for managing larger groups
Snowball	Start discussion in smaller groups and begin combining groups into larger groups, summarizing points, to finally reach a whole class discussion, Allows students to voice opinions in smaller groups and build up in stages to larger groups, and a whole class discussion. Effective for classes of mix-abilities, and allows less confident students to contribute

The second resource, “Get everyone involved” starts addressing possible issues of individual participation and provides strategies of solving such problems in a group activity.

Table 3: "Get Everyone Involved" Elements

Ground Rules	Set basic rules before discussion or participation starts, including respecting opinions, preventing interruption, careful body language, etc. Set a basic set of rules that every student can agree on.
Talking objects	Use talking objects or talk tokens to give a certain “right” to participating individuals.
Peer Observation	Empowering tool for students, give an active role to play. Use Socratic Seminar approach. Include observation sheets on new findings, disagreements, dominant speaking or lack of involvement, lack of listening etc.
Assigning Roles	Assign chairperson, facilitator, observer, and speaker roles to construct formatting of discussion and allow the students to govern themselves based in guidelines.
Recording and marking.	Record discussions with chart paper, mark brainstorming points, make sure individuals are given credits for coming up with certain opinions and ideas. Utilize tape recorders and video cameras to capture the discussion.

("The Science Museum: Classroom Resources," 2014)

2.6 Project Assessment and Evaluation

The informal learning environments where engineering outreach programmes often take place have many more variables than the formal learning environment students are used to. In order to ensure that these programmes are still reaching their educational goals, they often make use of a set of criteria to define the project purpose (Shah, 2013). Defining these criteria before the programme is implemented allows a curriculum developer to be focused on what defines success in an activity throughout the design process and into activity implementation.

The Dimensions of Success (DoS) is an observation tool developed by the National Science Foundation (NSF) in conjunction with the Program in Education, Afterschool and Resiliency (PEAR) to identify the quality of informal STEM programming (Table 4). By looking at this evaluation tool that is implemented during the delivery of a programme, the value of listing dimensions is established. A programme is more likely to meet dimensions that define a successful programme if these dimensions were in mind during the entire design process. The dimensions outlined below (Table 4) could not be taken directly as criteria for programme design because DoS is an assessment and evaluation tool that was not developed with programme design in mind.

Table 4: Dimensions of Success

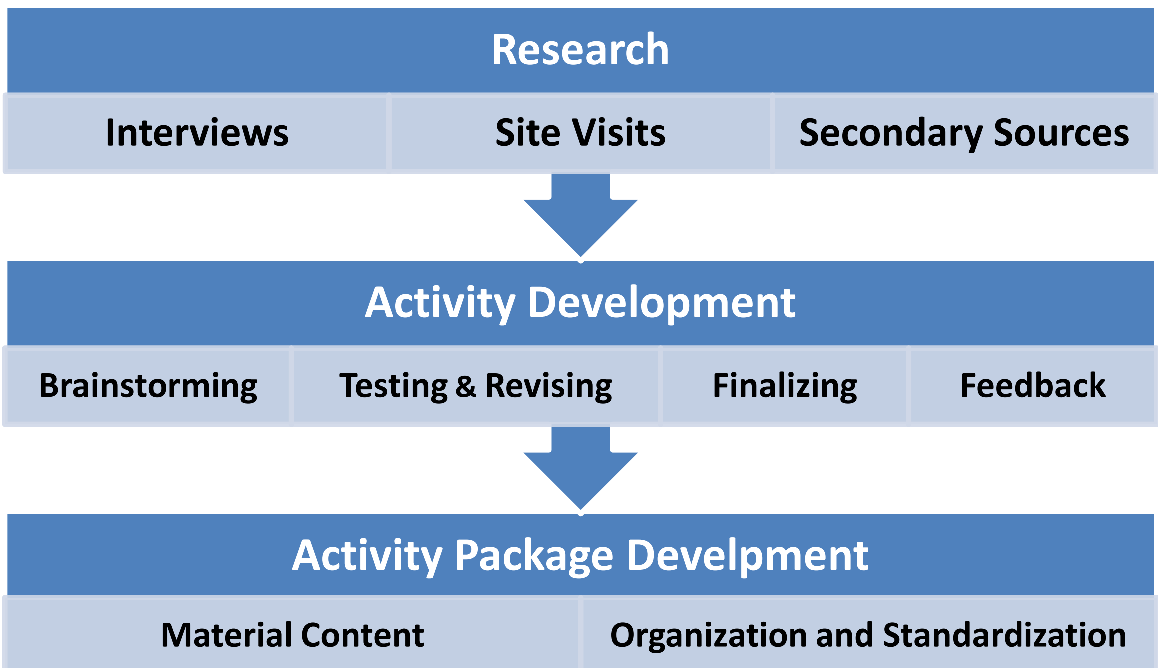
Features of the Learning Environment -Organization -Materials -Space Utilization	**Activity Engagement** -Participation -Purposeful Activities -Engagement with STEM
STEM Knowledge and Practices -STEM content learning -Inquiry/ STEM Practices -Reflection	**Youth Development** -Relationships -Relevance -Youth Voice

(Shah, 2013) s

Chapter 3: Methodology

The goal of this Interdisciplinary Qualifying Project (IQP) was to assist Young Crossrail in promoting STEM fields by developing hands on activities that can be presented by their volunteer ambassadors to a student audience. The overall project followed three phases to perform research and generate effective deliverables (Figure 5). Although all of these phases were followed throughout the project, they were not necessarily conducted simultaneously by all members in the group or in chronological order.

Figure 5: Flowchart of Methodology



There were three main phases to this IQP. In the Research phase we became familiar with the scope of our assignment by interacting with stakeholders involved in engineering, STEM outreach, and other education departments. Thematic findings from this research served as a foundation for the team to begin the Activity Development phase where potential activities were brainstormed and tested. Activity ideas were evaluated based on criteria that would determine the potential of the activity before advancing to the Activity Package Development phase where documents would be created to support the activity.

The timetable below (Figure 6) shows how these phases were conducted throughout the project period. Blue portions indicate tasks involved in the dedicated timeframe. As mentioned above, the phases, while following a general order, were executed simultaneously at times due to ongoing research and activity development.

Figure 6: Timetable

Week	1	2	3	4	5	6	7
Research							
Activity Development							
Package Development							

The project started on March 17th and ended on May 2nd, 2014. Young Crossrail provided the team with various resources, including Crossrail account access to personal computers, printing capabilities, and telephones, as well as personal workspaces at the Crossrail offices in Canary Wharf.

3.1 Stakeholder Interactions and Secondary Sources

Although the primary goal of the project was to devise hands-on activities and documents that assist their implementation, it was necessary to collect the information that would strongly support theses deliverables before experimentation could begin. Obtaining this information involved looking at primary sources by interacting with stakeholders through interviews, site visits, and focus groups. Stakeholders included Crossrail employees, Young Crossrail ambassadors and liaisons, and local partners who have worked closely with the Young Crossrail network in previous undertakings. We also looked at secondary sources that provided supporting knowledge, such as Young Crossrail's internal resources and the internet.

3.1.1 Interviews

In order to organize interview questions, stakeholders were broken into three categories according to how they had contributed to Young Crossrail in the past. These stakeholder categories include engineers, educators, and those who promote engineering in informal learning environments, including Young Crossrail. It's worth noting that some individual stakeholders belonged to more than one of these stakeholder groups. For example, a Young Crossrail ambassador who is a full time engineer or site manager and leads classroom activities at least once a month could field questions by representing all of the categories above. Of the 12 Young Crossrail ambassadors interviewed, 10 were professional engineers and 9 had led a classroom activity at least once every two months. The Education Officer of the Royal Festival Hall, Construction Teacher of Royal Greenwich University Technical Centre and the Vocational

Coordinator of Rokeby Preparatory School were also interviewed as education representatives who could field STEM outreach and student engagement questions. To maximize input from stakeholders, interviews were conducted in a semi-structured format that started by identifying which categories the interviewee fell under and proceeded with the accompanying category questions.

Engineering stakeholders were able to identify examples of engineering disciplines demonstrated within Crossrail and provide details about their professional experiences. Engineering examples were collected to serve a basis for activity development, giving us ideas that would have value in relating back to real life examples such as the Crossrail Project. Professional and personal details from the engineering stakeholders provided us with some motivations that engineers have, an important element that could be utilized to interest students in STEM fields. General questions used to find these examples include:

- Which STEM disciplines are most relevant to your job and how?
- What aspects of the Crossrail infrastructure project do you find most impressive?
- What other engineering jobs did you have before the current one?
- What motivated you towards a career in the engineering fields?

Stakeholder interviewees identified as educators provided general strategies to lead a classroom, and general insight of what an educator does. We attempted to identify useful engagement strategies for students, and possible issues that educators can run into in a classroom setting. We also asked about the motivation that educators have in teaching. Questions for this category of stakeholders include:

- What suggestions do you have for keeping students engaged in an activity?
- What is the worst classroom experience that you have had? How did you handle it?
- What is the most rewarding part of leading a classroom?

Stakeholders involved with other informal learning environments were asked questions that identify what ambassadors would need to conduct an activity based programme. Ambassador needs were valuable because our activities were to be delivered by a vast number of Young Crossrail ambassadors who come from various backgrounds and have different educational experiences.

- What tips would you give to help an ambassador who has never lead a classroom programme?
- What motivated your involvement in Young Crossrail or any similar organizations you have been involved with? How long have you been with this organization?

- How much time do you spend preparing to lead a classroom programme and how do you spend this time?
- What do you think about when choosing the programme you want to deliver?

There were some questions asked to all stakeholders because they were independent of categories. These questions focused on stakeholder input in our project objectives, or on identifying other valuable resources and interviewees who could further contribute to the growing research information that we were collecting.

- What do you think is the most important message that a Young Crossrail activity should deliver to the students?
- If a student asked about STEM field employment, what would you tell them? Where could they get more information?
- Which other stakeholders would you recommend interviewing?

3.1.2 Site Visits

In addition to these stakeholder specific interviews, we also observed and participated in events and site visits. These visits helped us understand how STEM outreach programmes are conducted, while allowing us to gain networking opportunities with related personnel.

We attended a Young Crossrail presentation held at the Elizabeth Garrett Anderson School, an all girls partner school working with Young Crossrail. The presentation was held by two female engineering ambassadors and promoted engineering to female students. We were able to observe how a session is run and to identify useful strategies of engaging students for use in our developing programme.

Visits to the Rokeby School and Greenwich University Technical College were made to visit other Young Crossrail partner schools. Here we identified general challenges that students pursuing the engineering path face, and observe what could motivate students to be engaged in STEM disciplines.

We took part in a STEM day held at the London Transport Museum, where we managed to connect with engineers who were engaged in the Crossrail project and other parts of Transport for London, as well as STEM teachers from around London. This was a key networking opportunity for us that led to our next site visit.

The Acton Apprentice Training Centre is a training site for future engineers taking the apprentice route, which provided us with details on one of the processes of becoming an engineer in the UK. The visit here was more targeted at gaining insight into the apprentice route, so that career path information could be added to our programme if necessary.

All of these visits had different research goals and were conducted by our project group together or in individual trips. It is also important to note that during certain visits, such as to the UTC Greenwich or the Acton Apprentice Training Centre, interviews with related personnel were also conducted to gather further information.

3.1.3 Secondary Sources

Electronic research was used to supplement the stakeholder interactions mentioned above. The Young Crossrail electronic archive, known as the U:/Drive, included existing activities from Young Crossrail and similar other organizations, and was coupled with internet research to conduct research into the status of the Crossrail project and other databases for STEM activities and projects. It was important to note the activities from third party organizations in the U:/Drive, such as the Science Museum or Transport for London, because their presence indicated that they embodied qualities that appealed to Young Crossrail. They were used in addition to the above stakeholder interactions to identify desirable qualities in activities.

Several online resources were also helpful in discovering and elaborating on Crossrail engineering examples. The Crossrail Connect website and Crossrail.co.uk were used along with Wikipedia to research Crossrail and rail transportation in general. They provided an extensive amount of logistical detail, alongside a vast image library which was used to accompany programme information in documents.

3.2. Activity Development

Activity Development followed a cyclic four step design process which involved brainstorming, testing, revising and finalizing, and collecting feedback. When other STEM outreach activities similar to ours were in this stage, they kept in mind a set of criteria to determine whether or not their activities were on the right path. One example of this is the Dimensions of Success mentioned in the Section 2.6, which showed how identifying criteria could effectively guide the design of a programme as well as its implementation (Shah, 2013).

3.2.1 Brainstorming Activity Ideas

The first step of the activity design process involved taking an aspect of Crossrail engineering that we identified through stakeholder interviews and research, and deriving an idea for an activity that communicates what engineering is and what engineers do. This process was conducted individually at first, with each member of the team taking notes on ideas that stemmed from critical thinking and applying research findings.

In doing this a, few main ideas were kept in mind and used as guidelines to adjust ideas while brainstorming. First, the activity has to be fit for classroom use and simple so that it can be understood quickly by students and ambassadors. Second, the subject matter of the engineering example is not intended to be comprehensive, but to show a specific engineering example within Crossrail that students can relate to (Cyr, 2014).

These ideas were then shared with the group and evaluated according to their relevance to Crossrail, whether they could be implemented, and whether the students would be able to perform the activity. We also analysed current activity packages from Young Crossrail and other similar organizations with attention to why they work and how they target specific subject matter.

3.2.2 Testing and Revising Activity Ideas

After an idea passed through brainstorming and the group agreed it had potential, it had to be put to practice. This step of activity design evaluated and tested materials that would be used by students to conduct these activities Material choices will determine the feasibility of an activity within the constraints of time and student ability levels. This strategy behind material selection would also allow students to participate and change their perceptions of engineering from something strictly academic to engaging and fun.

We purchased or collected materials and built prototypes to test if our initial ideas were actually feasible. They were considered successful if they could be completed in a short enough time frame and could accurately convey engineering principles to students without being too complicated. Initial prototype tests were critical to the identification of major problems with the activity idea. If any issues were identified, revisions were proposed to address them, and the prototype was tested again.

Materials from past activities were provided by Young Crossrail, and additional materials were purchased to test different activity designs. We first evaluated craft materials that students have easy access to at home. The use of household items (i.e. lollipop sticks and string) allows students to attempt their own crafts at home and lets them broaden their creative learning experience as they look for items around the house to suit a specific purpose they have in mind if they wanted to experiment further. Later, we evaluated materials that are more specific and complex, like kits or preassembled items. These allow us to make simplifications to household items and offer more potential in demonstrating STEM principles as students can shift their focus and time from crafting towards critical thinking. Surprisingly, experimenting with materials and trying out how they performed certain tasks sparked more activity ideas and allowed us to brainstorm our ideas further, or come up with new activity ideas that branched off of testing our initial ideas.

The length of an activity was also considered during the material selection process. For example, household items would have to be carefully considered and manipulated by students during the activity. This will take more time than preassembled kits or pieces, which would reduce the time required to complete a given activity, but also reduce the amount of creative design allowed during an activity.

3.2.3 Finalizing Activity Ideas

After an activity idea was tested and revised, we looked at what worked best in all of the tests and incorporated these things into a final challenge for the students during the activity. This challenge is the student's goal during the activity. It was carefully selected to ensure that the activity is appropriately difficult considering the ability level of the students and the time frame of the activity. In some places, we would then add specifications and design requirements to increase the complexity of the activity to cater to different audiences. To make decisions regarding the inclusion of these additional elements, we had to repeat tests and see how practically they could be implemented.

In this final step of activity design, we also began compiling troubleshooting notes on potential problems that could occur with the activities. Repeated testing gave us many failures alongside successful activity designs, both of which are equally important. We thought that such notes could be potentially provided as solutions to help ambassadors if the students were to run into the same issues. These troubleshooting elements would be incorporated in the documents we provide to the ambassadors.

3.2.4 Feedback on Activity Ideas

After activity ideas had been tested within our group, they were shown to stakeholders in two different forms: weekly meetings and an ambassador mixer. This feedback ensured that we were working within the needs of our liaisons and helped us to organize and move forward when we faced challenges associated with activity design.

Weekly meetings were held every Tuesday with our liaisons, Kate Myers and Lauren Hillier, and our advisors, Scott Jiusto and Laureen Elgert. At these meetings we received new information and input on our activity ideas and organization.

Aside from weekly meetings, an Ambassador Mixer was held on April 9, 2014, where some of our activities were tested on 16 ambassadors and our liaisons. We broke into four groups where four ambassadors were paired with one member of our IQP team. Adam Trumbley and Ashton Kim worked with two ambassador groups to implement one activity. Rachel Handel and Edward Li worked with two ambassador groups to implement a second activity. These groups were treated as focus groups. Their purpose is to represent all of the ambassadors involved in the program, whose input is valuable because they are the people presenting the activities.

Our liaisons sent out an email for the focus group to all ambassadors in their contact list, and those who were available during the time slot attended, therefore we did not have any choice as to participant selection. It is likely that the ambassadors who attended volunteer with Young Crossrail more than average. To prepare for the lesson we prepared two preliminary documents to show to the ambassadors about the activity: a student activity sheet and an ambassador guide. We looked for feedback from them in three areas:

1. Activity
2. Ambassador guide organization
3. Student activity sheet

Focus group questions were asked about an "informant's attitude" on these particular subjects (Dick, 2002). For example:

1. Do you think this activity will be fun for students?
2. Is this activity appropriately difficult for Key Stage 3 students?
3. Do you think any simplifications need to be made to the activity?
4. Is this activity gender neutral?
5. Is the ambassador template organized efficiently for you? If not, where can you suggest improvements?
6. Do you think students will find this student activity sheet useful?

While the focus group was taking place, it was also important to pursue explanations, just like an interview. This led to the informants in a direction to fully share their thoughts and opinions on something. Specifically, areas of agreement and disagreement were important because they revealed both the good and bad aspects of our project (Dick, 2002). Getting explanations in these areas will help us to revise our materials and make them better suit the ambassadors and the Young Crossrail community.

3.3 Activity Package Development

Once activity ideas evolved into hands-on activities, supporting documents were developed to communicate these ideas to all of our audiences. These supporting documents were named Programme Documents, and composed the Programme Package with the activities developed in Section 3.2.

3.3.1 Determining Document Content

As indicated by preliminary research, most projects similar to our own used supplemental documents to help guide the ambassador and student through a programme. Our Crossrail liaisons also asked for ambassador guides and student hand-outs to be included in programme packages. To determine the contents of these documents, we examined the needs of each of our audiences identified through stakeholder interviews and research. Focus groups and feedback from advisors and liaisons during weekly meetings were also used to identify and improve this content.

3.3.2 Organizing and Standardizing Document Content

Once we knew which content to include, it was organized into distinct documents pertaining to each audience (i.e. the student and the ambassador). Content was chosen to be adequately detailed while still remaining concise and following an intuitive progression throughout the lesson.

First, a progression, or general flow of each programme was defined based on our background research into the Worcester Education project, which covered distinct phases of a series of lessons (Ward, Fichter, Bradley, Bishop, & Rencis, 2004). We incorporated this into the scope of a single lesson, and devised the following four sections for each 1 hour and 30 minute programme to follow.

1. Introduction to Engineering Problem
2. STEM Background
3. Hands-on Activity
4. Discussion

This organization guided where information should go, and also became the basis of a timetable for each programme to run on.

Two considerations that emerged next were the number of materials presented to the audiences and the volume of each material. In order to avoid overwhelming audiences with information, we were careful not to repeat content. This led us to linking specific purposes to each document, ensuring that the entire package will cover the full scope of the project.

At first, documents were drafted individually so that each team member could brainstorm different ways to organize content among the different supplemental materials, while tailoring them to specific activities. This allowed various organization methods and documents structures to arise, much like when we were brainstorming our activity ideas. Eventually these different methods were collected and compared to see what elements were aesthetically pleasing, while fulfilling our audiences' needs and allowing each document to work effectively with others in the package. Additional feedback was gathered from our liaisons and ambassadors.

Chapter 4: Research Analysis and Criteria Development

Since assessment and evaluation tools define qualities of good programming, criteria should be developed for the programming development process. Criteria represent qualities that programmes should embody and when programmes are assessed and evaluated for success it is these qualities that programmes are judged on. Programming developed in this IQP should strive to perform well with regards to criteria like the Dimensions of Success (Section 2.6).

In this section we will discuss how stakeholder interviews, site visits, and focus groups helped inform the development of criteria for programme design. For this discussion we will provide thematic obstacles that we found and possible approaches to address them that can be incorporated into programme development. These criteria can be grouped into two categories (Figure 7). The first category is aimed at how students receive the programme, these student criteria are student engagement, adaptability, and variety. The second category considers ambassadors as they deliver or prepare to deliver the programme and include ease of use, ambassador freedom, and practicality. The needs of the students affect the needs of the ambassador so that some of the ambassador criteria are informed by the student criteria.

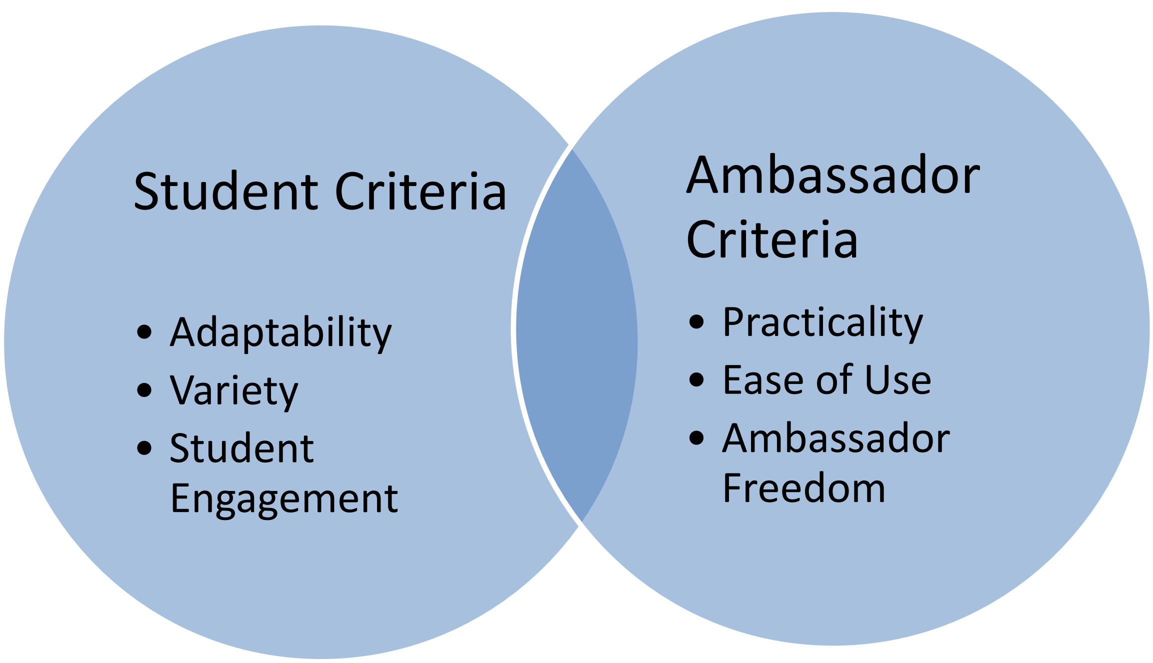


Figure 7: Programme Development Criteria

4.1: Adaptability, Variety, and Student Engagement

Approaches to Criteria:

- Include messages about diversity throughout programme delivery to address student variety within a particular classroom.
- Provide activity adaptability to programmes by offering a mechanism to accommodate student ability levels found across classrooms via a layered complexity scheme.
- Highlight areas of the Crossrail project for student engagement by showing that STEM is not just studied for the GCSEs and give a better understanding of engineering professions.

The Young Crossrail programme delivers programmes to a variety of classes and school groups. This means that there is a broad range of ethnic diversity, ability levels, learning styles, and interests within any particular classroom. Students often have a poor understanding of the STEM professions, especially in the engineering fields. These poor understandings of the responsibilities of professional engineers and other related careers often has roots in a poor understanding of these careers by parents and even teachers, who often push their students towards other career paths such as medicine and law.

Universities in the United Kingdom experience a high turnover rate within engineering due to the misinformation about engineering careers received by students earlier in their lives. There have been recent initiatives within the Young Crossrail pool of ambassadors to offer shadowing opportunities to university students. Educational representatives stated that many students feel that they are only learning maths and science subjects for the sake of doing well on GCSEs, and eventually displayed disinterest in the classroom (H. Cox, personal communication, March 21, 2014).

Ambassadors accredited the abuse of the word ‘engineer’ in the United Kingdom for the way that students perceive a career in STEM fields. Since ‘engineer’ is used more liberally than in other countries there is a misconception that engineering is dirty work meant for men who wear hard hats and high visibility uniforms (G. Purcell, personal communication, April 2, 2014). For example the title ‘sanitation engineer’ refers to garbage men. A title like ‘civil engineer’ is not as respected in the United Kingdom as it is in other European countries because a ‘civil engineer’ might be mistaken for a social or government worker. One objective of interviews with professional engineers was identifying aspects and processes within the Crossrail project that would intrigue the average student. The majority of those interviewed were impressed by the scope of the infrastructure project and necessary logistics involved with interfacing all contractors contributing to it. Many of those interviewed added that they were impressed with project expectations considering all of the operation constraints. For example, the Whitechapel station was excavating dozens of meters away from a school, over ground rail system, and food market without disturbing the integrity of these structures or emitting too much noise and debris into the environment (A. Heaton- Renshaw, personal communication, April 2, 2014). More specific examples of impressive engineering include the screen and door systems, like those on

Jubilee Line platforms, because they involve many disciplines all at once, including mechanical and electrical engineering, safety, and systems integration, while requiring a higher level of collaboration between Transport for London and Crossrail (R. Cox, personal communication, April 4, 2014). Another interesting aspect of the Crossrail project is the Building Infrastructure Modelling (BIM) system, which is a database that details every component of the Crossrail project, and features a barcode system which catalogues every piece of the infrastructure project (M. McIntyre, personal communication, April 2, 2014). Ambassadors also suggested finding some impressive aspect within pieces of the infrastructure project that students would see often. The most readily visible aspects of the Crossrail infrastructure project are the station construction sites, tracks, and carriages (G. Miles, personal communication, March 26, 2014).

Highlighting many areas of the infrastructure project through the Young Crossrail activity portfolio helps to show students the scope of the Crossrail infrastructure project. As mentioned in the background chapter liaisons communicated the importance of having the designed activities relevant to Crossrail (Hillier, 2014c). By showing students how vast Crossrail is, students are exposed to the opportunities that engineering fields can provide and allow them to understand what engineers contribute to (G. Miles, personal communication, March 26, 2014). Engineering is about being creative and one way that students can exercise these skills is by manipulating materials around them. Just as materials used in real applications are highly engineered, students can learn to think about the properties of a material, and how they can be used to suit a purpose (R. Cox, personal communication, April 4, 2014).

Ambassadors who are professional engineers felt that they need to convey real day to day aspects of their career and mentioned that relatively few engineers are pure mathematicians and scientists by trade. The average engineers are each a “jack of all trades,” meaning they are multidisciplinary within the STEM fields and interdisciplinary with interpersonal skills needed for presentations, management, and collaboration (S. McElroy, personal communication, March 20, 2014). There are also many ways into a career in engineering meaning there is no prescribed path or preferred personality archetype necessary to strive towards one of these careers. (S. Miller, personal communication, April 2, 2014). Many ambassadors also said that a good foundation in maths and science will open doors. These subjects are a valuable selling point to any employer even if the position is not immediately relevant to the STEM fields. A career as an engineer can take them anywhere they choose geographically because engineering is likely relevant wherever they want to go (G. Purcell, personal communication, April 2, 2014).

A more direct way to engage students while emphasizing the prevalence of STEM around them would be to ask students what their hobbies are or what they see themselves doing when they are finished with school. Likely their hobbies and goals can be related to the STEM fields and framing maths and sciences around these contexts would help show them that maths and sciences are relevant outside of GCSEs (H. Cox, personal communication, March 21, 2014).

Another notable approach mentioned among the majority of ambassadors was to make activities thought based instead of learning based. The best activities would be ones that encouraged students to use what they are learning or already know from day to day experiences to make new discoveries which would show them that maths and science can be used to explain what they see around them (L. Highe, personal communication, April 1, 2014). From literature review, it would be best to replicate a real engineering challenge and have students problem solve in a way that they would relate to the material ("Curricular Unit: Creative Engineering Design," 2014).

Young Crossrail does not have much control over some variables like student ability levels of some of the classrooms or sometimes even the length of time ambassadors have to deliver a programme depending on the event. The target audience of this programming is Key Stage 3 students (Ages 11-14). This means that each activity developed must be designed to be adaptable within the variety that Key Stage 3 offers. Students on the younger end of the spectrum who are eleven years old think and behave differently from those who are fourteen years old. Ambassadors more experienced in leading classrooms were questioned on how to approach students to ensure that the point of the activity will be received. Most ambassadors said that different ability and engagement levels should be kept in mind while designing. There is a spectrum of students where some Key Stage 3 classrooms may include barely literate students unable to convert grams to kilograms, while there may be other classrooms full of students participating in coding club afterschool. It is also likely that the full spectrum may be found in the same classroom (L. Highe, personal communication, April 1, 2014). When ambassadors gave feedback for some activities in a focus group setting they mentioned that certain skills that activities are based on may be familiar to older students but younger students still may not be able to conceptualize these skills. Therefore activities need to be simplified and additional layers of explanations may be needed to adapt to the audience the activity will be presented to. An activity should also be capable of being altered in terms of tasks to provide new challenges or reduce difficulty in the event that an activity is either too difficult or easy for a given student audience. Because of these independent variables, layered structures to activities were considered where layers could be added or removed based to adapt to different ability levels and time requirements (L. Highe, personal communication, April 1, 2014).

Another concern from ambassadors relating to adaptability was that activities may not run their expected paths. Some tasks may be finished too fast, while certain circumstances may lead students to be unable to generate a resulting product for the activity. Ambassadors expressed concern that this may cause students to appreciate them and the programme less, thus causing disengagement (G. Purcell, personal communication, April 2, 2014). To address both ends of the engagement and ability spectrum, simple base activities should be considered allowing ambassadors to add layers of difficulty to suit higher performing and more engaged students. Thus, each activity should not only have an incorporated option to control difficulty, but also be relatively failure-free (L. Highe, personal communication, April 1, 2014).

By adding curveballs as the lesson progresses an ambassador pointed out that the programme would simulate real world engineering where professional engineers occasionally stumble on constraints that no one predicted (G. Purcell, personal communication, April 2, 2014). This approach can be used to cater to more advanced students, while a version of the activity without curveballs would other ability levels.

Targeted messages to specific demographics should be avoided when designing activities since attendance of the demographic is not easily predicted. Embedded messages should be used instead to avoid tailoring activities towards specific groups. The consistency embedded messages provides also makes the presentation easier for the ambassadors.

Embedded messages consistent throughout all classroom ambassador presentations are effective because classrooms are rarely made of students that can be defined under the same demographic (S. McElroy, personal communication, March 20, 2014). It is rare that a classroom will be made up entirely of female students. However parts of the presentation which address female engineers should be included in every presentation because a significant amount of female students would receive the message each presentation.

4.2: Practicality, Ease of Use, and Ambassador Freedom

Approaches to Criteria:

- Create practical activities by developing around times constraints and student abilities.
- Create a standard programme package to guide ambassadors through programme delivery for each activity so that programmes are easy to use.
- Provide ambassadors with the freedom to modify programming to reflect their personality and personal messages.

Practicality is a consideration of whether students would be able to meet the challenges that they would be faced with in activities. This consideration encompassed time restraints, what students could be expected to have already learned, and crafting ability of students. All activities needed to be delivered within a one hour and thirty minute time window, which is the typical time allotment for such activities at Young Crossrail's partner schools. The presentation and use of each activity is facilitated primarily by ambassadors to Key Stage 3 students, meaning that all activities needed to be designed towards an eleven to fourteen year old audience. Location, or learning environment, was the final limitation, as every school is different, and sometimes activities are used as a part of STEM days hosted by local museums and organizations for area students, meaning the activities must be practical in the sense that they can be adapted to a variety of learning environments.

Each programme must be developed under sets of limitations which include the time allotted, ability level of the student audience, and learning environment. Ensuring that all activities are designed to operate within these limitations is critical to effective activity delivery. Some Young Crossrail ambassadors were also concerned that many existing activities similar to our programme lack advice on running the activity in a way that engages their student audience. This has led to certain activities being disused or used with a reduced student impact.

Our liaisons specified an hour and thirty minutes for the execution of each programme including introduction to engineering, background information, student challenge and discussion

(K. Myers, personal communication, March 24, 2014). This time restriction allows the ambassador approximately forty to fifty minutes to run the activity. Within this time restriction, ambassadors could not be expected to formally teach students engineering concepts that students did not already know. The best activities would take what students already knew and show them new ways to apply it to make new discoveries (L. Highe, personal communication, April 1, 2014). For information regarding what students could be expected to already know, the National Curriculum (Appendix A) was referred to (Education, 2013).

The crafting ability of the students was considered next. Much of this remaining forty to fifty minutes to run the activity must be used valuably to ensure that the message of the programme is delivered to the students. Therefore activities could not demand a high level of crafting ability from students because they would be focused on crafting rather than receiving intended message. Crafting ability of the students could not be controlled but materials that are given to the students can. Through rigorous testing of the different activities we developed, we realized that certain materials and activity designs were impractical for this time range because they were too difficult for the average student to manipulate. For example, wood crafts with wood glue, or construction with papier-mâché are engaging and creative, but take too much time for any practical result to come out in forty minutes. The level of complexity in the activity would have to be controlled so that the given time enables students to have a well-rounded experience.

The problem of student impact was approached by considering how the programme is structured and how the programme is delivered to the students. The programme structure is only part of what the students see and the rest depends on how the ambassadors deliver the programme. Since the personality of the ambassador is usually the most engaging part of an activity when it is delivered, promoting ambassador freedom promotes student engagement (H. McPherson, personal communication, March 25, 2014). Student engagement can also be addressed by offering general strategies to ambassadors in supporting documents and suggesting optional prompting questions that are meant to engage a student audience.

Sometimes ambassadors do not have much time to prepare for delivering a programme. After all, the Young Crossrail ambassador network is made up of full time employees and their jobs at Crossrail are priority (A. Shad, personal communication, March 24, 2014). Ambassadors usually do not lead a classroom activity often enough to become familiar with a complicated set of documents to be comfortable enough to run an activity. It is impractical to advise that Young Crossrail have training sessions for their ambassadors on how to navigate through the Young Crossrail portfolio. Therefore each programme would have to be designed with supporting documents that are intuitively understood. Each of the activities developed must be detailed and structured enough with suggestions and optional resources that less experienced ambassador could fall back on. Suggestions and optional resources are preferred over rigid instruction to avoid stifling the ambassador (H. McPherson, personal communication, March 25, 2014). The programmes should be designed to invite the ambassadors to customize some parts of the activity and allow adjustments anywhere else while making sure that they understand the objectives that are meant to be communicated to the students. The written documents supporting the programme should not be a concrete set of instructions. It was understood that non-flexible instructions could potentially patronize the ambassadors and interrupt their own styles of presenting to students and conducting activities (K. El-Hakim, personal communication, April 2, 2014). The materials should be informative, but should allow the ambassadors to incorporate their own experience and ideas into the presentation of the activity. Ambassadors often have their own messages that they want to put forth to students about the engineering fields (S. Miller, personal communication, April 2, 2014). These messages are often the most important part of the programme since they can be a key mechanism towards breaking stereotypes that are attached to engineers and show students that engineering creative and collaborative (S. McElroy, personal communication, March 20, 2014).

One of Young Crossrail's issues with ambassador involvement is that many are intimidated by the idea of presenting in a classroom (H. McPherson, personal communication, March 25, 2014). By giving ambassadors the freedom to make the activity their own, we can also provide the ambassadors with a higher level of confidence, allowing the activity to have a stronger impact on both students and ambassadors. Written information conveyed to the ambassadors must be effective and clear because ambassadors cannot be assumed to have engineering experience or have led a classroom activity before (S. Miller, personal communication, April 2, 2014). Although the information must be comprehensive, it is important that the information is concise to make preparing for the programme easy.

Interviewees also mentioned that ambassadors may be less compelled to lead a classroom where they feel unappreciated, which can be addressed by the structure of the programme. When asked to consider the programme structure, ambassadors noticed a correlation between opportunities of failure within an activity and student disengagement, so their suggestions leaned towards making activities as 'failure free' as possible (L. Highe, personal communication, April 1, 2014). At the same time there were also ambassadors who insisted that activities be competition based to simulate real world engineering environments and motivate students (K. El-Hakim, S. Miller, personal communication, April 2, 2014). This competition element inherently introduces the possibility of failure. A few others mentioned that a possible compromise would be competing against a baseline statistic and not against other classmates (A. Shad, personal communication, March 24, 2014). If the activity is competition based, ambassadors suggested designing a rubric and having a point system based on this rubric so that students would know which aspects they are being scored on (A. Heaton-Renshaw, personal communication, April 2, 2014).

Another way to address this disengagement is for ambassadors to avoid singling out students who may be shy. This can be done by dividing a classroom into groups, each made of a few students, and posing a question to groups instead of individuals so that quieter students would still be able to participate without feeling like they are in the spotlight (H. Cox, personal communication, March 21, 2014). Together, increased student and ambassador engagement levels are both key to effective programming.

4.3: Keys to Success and Mechanisms of Failure

The criteria and findings above played a vital role in inspiring and guiding our activity development. Activities were conceived from the ideas of ambassadors and were then developed, tested, and revised to meet the above criteria and address all of the concerns raised during stakeholder interactions. By testing and revising activities, we were able to identify a number of keys to success as well as failure mechanisms that determine how successful the activity is. These keys and mechanisms span a range of principles from the level of creativity promoted to the task complexity and challenges posed by an activity which are further explained throughout this chapter.

Concept Relevance

The impact of a programme depends on how well students can relate the engineering concepts covered to real world examples because students who are able to relate engineering concepts are more likely to be engaged. Therefore, one of the biggest factors in determining the success or failure of an activity is the relevance of the presented concepts and skills to real world applications. The presented programme content must be relevant to real world applications within the Crossrail infrastructure project. In our case, successful activities are those that can bring elements such as project management and structural design from the Crossrail project and incorporate them into hands-on programming. If elements of the real world and aspects of the Crossrail project are embedded throughout the programme, the risk of student disengagement is greatly reduced and results in a more powerful activity that will impact a broader range of students.

Material Selection and the Promotion of Creativity

A major factor in designing the materials list for individual activities was the result of an interview with an ambassador involved in the London Transport Museum who stated that the activities developed in this IQP should take advantage of not being based around a specific museum exhibit. He recommended using materials that could be found around the house so that students could craft spontaneously (R. Cox, personal communication, April 4, 2014). He was addressing the adaptability of a programme. We also addressed adaptability as well as variety when we were thinking about materials. Another aspect that was considered was the overall cost and usefulness of the materials. This also brought into question whether materials could be reused or if they could be applied in different ways. For example, reusable materials such as LEGO or K'Nex may have a larger initial cost, but can be used over and over. They allow students to focus on the engineering process because they are using prepared materials which are familiar and have fixed properties.

Lollipop sticks were one of the first materials used in all construction-based activities. Lollipop sticks proved to be practical for certain types of construction such as small vehicle frames but due to the joint construction aspect of structure building, they proved unsuitable for use in any of our larger scale construction activities, especially if the structure was required to bear a load. The primary failure mechanism with the lollipop sticks in structural applications was not the sticks themselves, but rather the materials used to form the structural joints. Bonding materials either took too long to cure to be practical (as was the case with wood glue) or failed to secure the joint (as in the case of the Play-Doh, which does not have the structural integrity to secure two load bearing members of a scaffold).

Another element of material selection has to do with the quantity of each item that is allotted to a team. It is easy to make too obvious and also restrict the possible number of solutions by allotting a minimal amount of supplies. It is also easy to overcomplicate the challenge by providing too many construction options, leading to failure by causing teams to work too much on experimenting and planning rather than constructing a final working product.

It has been found that students often feel a stronger connection to an activity which inspires them to think creatively in order to complete a task or challenge. Limiting the amount of materials allotted to each student team promotes creativity and innovation. It teaches students the importance of careful planning and designing, as well as how to optimize the use of resources. Promoting creativity also engages and holds the students' attention better throughout the course of an activity because it forces them to keep an active mind throughout the learning process. This added benefit means that appropriate material selection and quantity limitation leads to increased student engagement in the team project, subsequently leading to a greater impact of the STEM concepts and principles presented during the activity as a whole.

Task Alteration, Time Management, and Division of Labour

An appropriate level of activity content detail and task complexity was one of the major findings that resulted from testing our activities and directly contributes to how practical an activity is. In every activity, there was a question of how detailed the definitions and descriptions of STEM concepts needed to be. During the Ambassador Mixer event, this was one of the major areas of discussion. In some cases, the ambassadors were worried that vocabulary choices to explain tasks may have been at too high of a level for some students. They emphasized the need to include pictures in ambassador presentations and activity sheets to represent tasks, as well as reword the tasks in all activity materials so that they could be more easily explained by ambassadors and understood by the students.

For many of our activities, the ambassadors felt the complexity level of the challenge was appropriate was as important as wording explanations to suit Key Stage 3 students. In other cases, the challenges were age appropriate, but the task complexity was too great for the time constraints we needed to operate within. Activities need to be designed to fit within a ninety minute time frame, with only forty to fifty minutes devoted to the team project or challenge. Any activities that demanded more time than this would not be practical for Young Crossrail After testing some activities multiple times, the tasks that need to be completed by the student teams had been modified and simplified in multiple ways to ensure that student creativity was promoted along with the need to create a final model or product from the given set of “household” materials within the allotted time. With some activities, there came the problem of construction complexity. One activity was an attempt to modify an existing Crossrail activity known as the Crane Activity. The crane was developed by an ambassador, but was designed for a two hour time window, and the complexity of construction and prior knowledge of some of the STEM material required by the ambassador has led to the activity’s disuse. Though some activities were not pursued due to time and structural complexity issues, using K’Nex or similar construction toys could drastically reduce the construction time required to facilitate an activity and allow for its use in a classroom setting.

With certain tasks, the issue of time constraints and complex tasks was addressed by simplifying or modifying the task. The first approach that addressed time and complexity involved an emphasis on a timeline for groups to follow. By structuring a group’s time, we can ensure that students keep focused on completing certain elements such as planning early enough to leave time to effectively construct or implement their plans. Another approach was to divide the groups into independent “professions” and roles. By dividing the students into focused roles within the group, a complex or multi-faceted activity can be completed within the designated time frame by allowing students to focus on specific areas of the task and also promote collaboration between group members while showing them how engineering works in the real world. The third approach was to eliminate some of the tasks from the group activity in order to keep groups in control of how to divide labour and manage their time, but allow for them to focus on only one element of an activity.

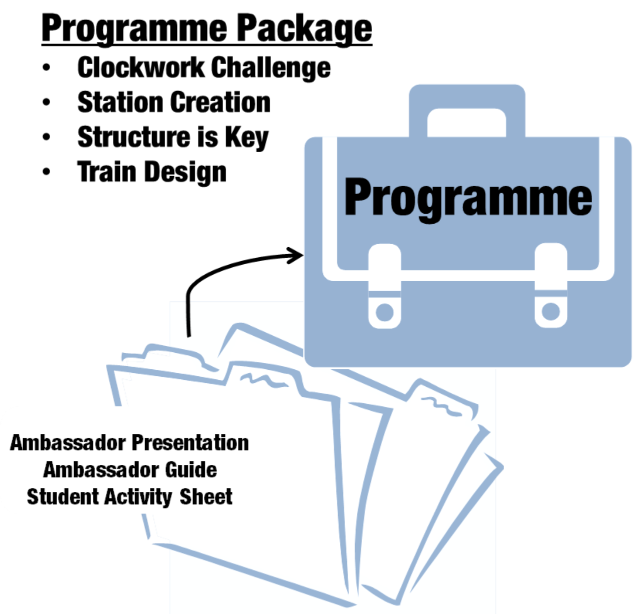
Tangible Results

Through an Ambassador Mixer, we found that with some activities we were developing, there was a lack of tangible results for students to be engaged in creating. This need for a highly tangible team project or challenge in every activity was not fully realized until we reached the testing phase of activity development. One of the key reasons why certain activities are successful is the inclusion of a reinforcing activity with strong hands-on construction or creation elements that are helpful in addressing student engagement. One of the best ways to solidify presentation materials and make them memorable to students is to let the students apply the principles they just learned. This reinforces the material presented and gives the students a chance to build and understand how the STEM concepts apply to real world challenges and problems.

Chapter 5: Programme Package

This research and criteria culminated in the development of our main deliverable, the Programme Package. It is composed of four programmes: Clockwork Challenge, Station Creation, Structure is Key, and Train Design. As shown below in Figure 8, each programme contains a suite of three documents: an Ambassador Presentation, Ambassador Lesson Guide, and Student Activity Sheet. These three documents assist the ambassador in effectively delivering an activity to their student audience. They also abide by a standardized format where possible, so they can be used in the future as a template to develop new activities. This standardized format and its accompanying rationale is explained in this section, including how the Programme Package relates to criteria described in Section 4.2.

Figure 8: Programme Package Organization



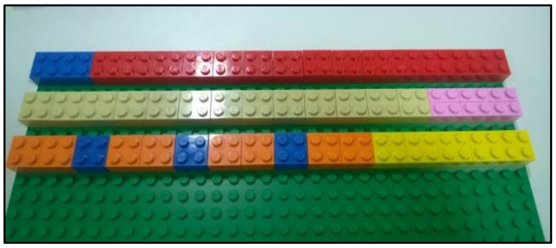
5.1: Activity Descriptions

This section introduces each activity we developed as part of Young Crossrail's STEM outreach programming. It will include a synopsis of the student challenge and related STEM concepts. Each of these activities draws on information from Chapter 4 to present an engineering concept related to the Crossrail project. This project is something that the students can see every day throughout London, thus it is an effective connection between daily life and STEM concepts that the kids will retain long after the lesson has ended (Mansour, 2009).

Clockwork Challenge

The Clockwork Challenge requires students to efficiently plan out the construction of a railway station using pen, paper, and a Gannt chart made of LEGO bricks (Figure 9). It involves project management and maths, with a focus on logical problem solving and organizing work schedules.

Figure 9: Legos which students will use to create a Gannt chart during the Clockwork Challenge activity to plan out station construction



Students, in groups of 3-5, are asked to organize a timetable for six different tasks to be completed at a station construction site. These tasks range from masonry to electrics to plumbing. Tasks are designated different lengths of time to finish, ranging from 30 days to 100 days, and the students are required to fit the different tasks into a timetable to build the station in a minimal number of days. The timetable allows three tasks to be finished simultaneously, while there are certain limitations to the execution of tasks, including certain tasks unable to be done at the same time, or a certain task having to be started after another is finished.

The students will be given a set of colour coded Lego bricks; each task is represented by one colour and each brick represents 5 days of work. Students will be expected to graphically express the schedules with three lines of Lego bricks on a provided Lego board. Students are expected to construct a fully formulated schedule within a limited amount of time.

Once an initial activity time period of 35 is finished, there is an additional time range where the ambassador has the choice of adding additional challenges. These challenges, such as work delays to the project, would freeze a certain number of scheduled workdays while forcing students to reschedule the remaining task days according to the new conditions.

For the task, the student group will be required to work as a team, incorporating logical thinking, simple maths, and solving a graphical puzzle while understanding the difficulties of managing a construction project. Students will also be introduced to the concept of a timetable in a graphical, hands-on manner, while learning to optimize efficiency within certain limitations.

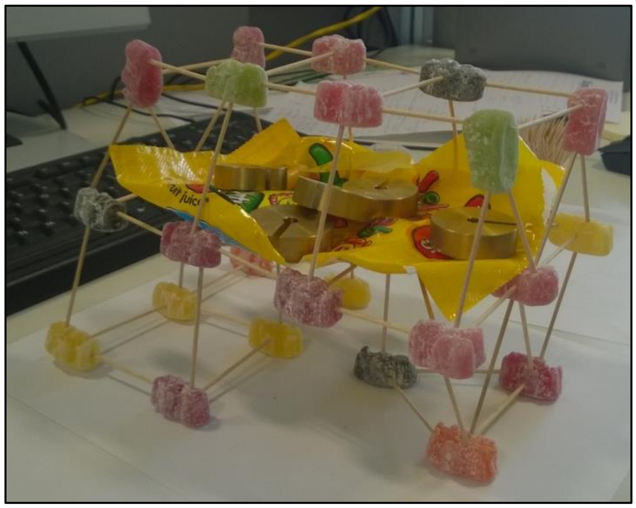
To accompany the activity, background information focused on project management, and a brief description of the different contracted work involved in a single construction project shall be provided. Students will also be exposed to the concept of scheduling work shifts and creating a Gantt chart.

For more information on the Clockwork Challenge, see Appendix C which contains activity package documents.

Station Creation

The Station Creation activity has students build a sturdy railway station out of tooth picks and jelly babies (Figure 10). It focuses on Architectural Design and Civil Engineering, with an emphasis on structural design in the construction of large buildings and structures.

Figure 10: The station cration activity has studetns build a structure out of toothpicks and jelly babies to hold weights on its first "floor"



The activity divides students into groups of 4-6, and then further divides each group into four roles: Architect, Engineer, Site Manager, and Project Manager. Each group is asked to design and build a model railway station from the ground level up, containing at least one suspended level that must support 0.5 kg of weight. The station must designed, and then be built out of toothpicks, jelly babies, masking tape, and A4 paper within a 50 minute time limit.

The material selection and role division place an emphasis on collaboration between “professions” in order to make a design a reality within a specified window of time.

The final element of this activity involves the preparation of a 2-3 minute presentation in the form of an “elevator pitch” in order to explain their design and construction processes.

For more information on the Station Creation, see Appendix D which contains activity package documents.

Structure is Key

The Structure is Key activity requires that students strategically construct simple structures from paper (Figure 11). It is focused on Civil Engineering disciplines, especially kinematic physics and material science related to structural support in buildings and large structures. It requires students to think innovatively and creatively.

Figure 11: A successful model of the Station Creation bridge made out of two sheets of paper that holds over 1 kilogram of weight

The activity places students in groups of 3-4 to design, build, and test structures that perform specific tasks. Each group is given two primary tasks focused on creating paper structures that are capable of supporting weights under certain circumstances described below.

The first task requires the students to build a paper platform that supports 1kg of weight and stands at least 8cm tall, using a single sheet of A4 paper divided into 8 equal pieces. Students will be given access to rulers, scissors, and masking tape. When finished with this task, the students are given materials to accomplish the second task.

The second task involves building a paper bridge that lies across a 15cm gap between two platforms out of one single sheet of A4 paper. The masking tape will be taken away for this task.

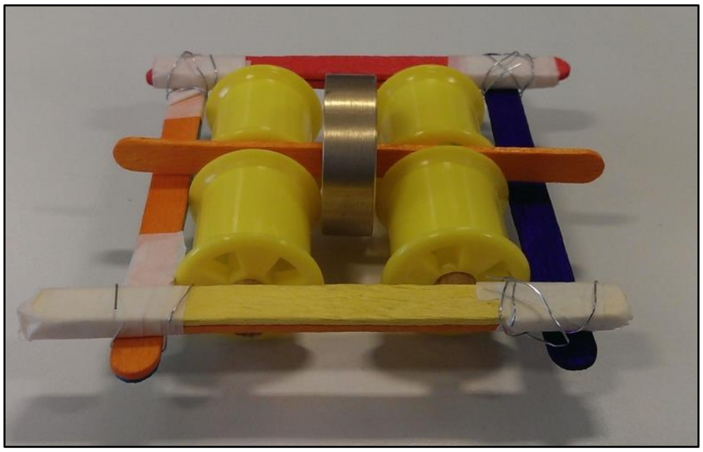
For each task, the student group will have access to backup supplies in case their sheets of paper rip accidentally, but the final structures can only be made with a limited amount of materials. Students will be required to exercise caution in handling materials to build structures, while also considering the material limitation to fulfil a given task. Students will gain exposure to new applications and characteristics of a familiar material such as paper, and will also learn to work in a group, accomplishing a single goal, and also competing with others as groups.

For more information on Structure is Key, see Appendix E which contains activity package documents.

Train Design

The Train Design activity has students build a train car from crafting materials that they then test on a railway (Figure 12). It is focused on Railway Engineering and Mechanical Engineering, especially focusing on the design of a railway car and maintaining safety standards. It requires that students learn by trial and error.

Figure 12: One example of a train car for the Train Design activity utilizing lollipop sticks, tape, wire, spools, and dowels



The activity places students in groups of 2-3 to design, build, and test a train car that will run down a predetermined rail track when attached to their classmates train cars via hooks. Students will be given a prescribed set of materials including lollipop sticks, masking tape, wire, paper clips, wooden dowels, and plastic spools to create each train car.

Students will be asked to create each individual car in groups, and then come together as a class to connect the cars. There will be a fixed set of specifications including the length of the car and the position of the hooks that connect the different cars. The cars will be required to roll, not slide, down the track and also run straight, ensuring that they will not derail. This process will demonstrate how engineers work together in different factions towards one common goal. Engineering principles such as designing, building, and testing a structure shall also be emphasized to the students in implementing the activity.

There is a time and material limitation which teaches students key engineering principles like efficiency and optimization. Students will be required to apply STEM background provided during the presentation to solve these problems and complete the project. Each group will have to work as a team to accomplish a complicated task.

For more information on Train Design, see Appendix F which contains activity package documents.

5.2 Programme Documentation

Each programme has guidelines that will provide necessary details to our audiences on how to implement the programme. Preliminary research and interviews suggested that these guidelines have to be for both the ambassadors and students, in addition to our liaisons. Ambassadors will need an entire lesson laid out for them with guidance on how to hit major learning objectives and how to facilitate student teamwork, among other things. Students will need a hand out that will summarize basic ideas associated with the activity. Analysing these audience requirements led us to the development of three documents: an Ambassador Presentation, Ambassador Guidelines, and a Student Activity Sheet. Each activity will have its own bespoke set of these documents, though much of the format and content was standardized by evaluating documents developed in past IQPs (Zoll et al., 2008; Ward, Fichter, Bradley, Bishop, & Rencis, 2004). Additional recommendations for our liaisons are provided in Appendix G; this information will help prepare programmes for ambassador use. This standardized content is discussed below including input from research, interviews, and criteria.

5.2.1: Ambassador Presentation

The most crucial element of the activity package will be the Ambassador Presentation. This takes the form of a PowerPoint and is the backbone of the entire lesson, providing a general layout of the programme and key visual elements to aid the ambassadors before and during the programme.

Each presentation will follow a standardized format, moving through four phases as indicated by a colour. This outline can be seen in Table 5 below. In the Introduction phase we focus mainly on learning objectives around engineering and Crossrail. In the STEM Background phase we prepare students with concepts for the activity to come. This is followed up by an activity description which the activity will follow. Students will then discuss the activity afterward to reflect on what they have learned and applied during the activity.

Table 5: Four Phases of Ambassador Presentation

Section	Colour	Content
Introduction	**GREEN**	Introduction of the Ambassador What do Engineers do? What is Crossrail? What is the engineering challenge for this activity?
STEM Background	**PINK**	Presentation of scientific and engineering principles necessary to understand the engineering problem and execute the activity
Activity	**BLUE**	Activity Instructions, requirements, rules, and any tips that could assist students
Discussion and Summary	**YELLOW**	Discussion questions and prompts, summary and additional recommendations

The structure of every PowerPoint has been standardized for most of the Introduction section so that it is easy to understand, use, and replicate. Some of these standardized slides will be presented here as one of our major project results. The general flow of these presentation slides follows this format:

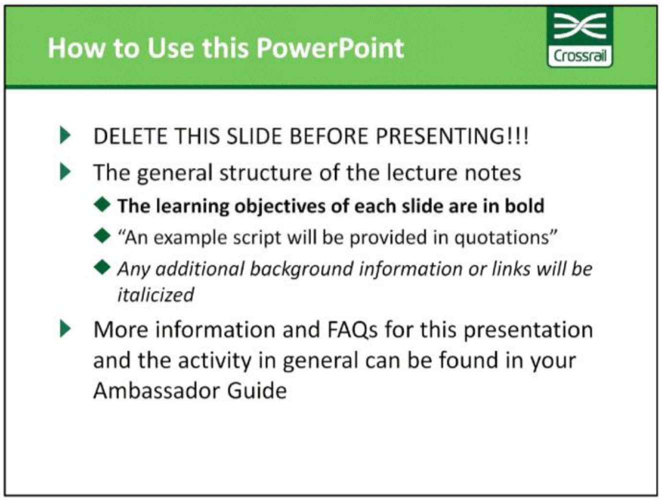
- Ambassador Guidelines (Slide 2)
- Ambassador Introduction (Slide 3)
- Engineering Introduction (Slides 4 and 5)

Each slide shown here will be explained in detail, including the rationale behind its content and how it is presented. Some slides will explain a rationale based on the slide as a whole, whereas others will provide a rationale based on individual objectives. This rationale has been derived directly from preliminary research and interview findings, as described in Section 3.1.

One key aim of the Ambassador Presentation is to make an activity presentable by every ambassador, regardless of their professional background. This is a need that was identified early on, as the content of these lessons is STEM related but many ambassadors come from marketing or human resources backgrounds (L. Hillier, personal communication, March 20, 2014).

Slide 2

PowerPoint Slide 2, presenting an introduction for ambassadors on how to use the document



Slide 2, above, is the second slide of every PowerPoint presentation. It shows ambassadors how to use the notes on every slide of the presentation which will lead them through the entire programme. All major lesson objectives, guidelines and additional information have been incorporated into the lecture notes of the PowerPoint slides. The lecture notes will consist of three sections: **Learning Objectives, Example Script, and Supplemental Information.** These will provide the ambassador with information on what the slide should communicate, how it should be done, and any additional information that can be applied.

Learning Objectives

The objectives of each slide are written as the first part of the lecture notes in boldfaced text. These objectives are learning outcomes for each slide, i.e. the things students should understand when the ambassador has finished presenting. They are the framework that the rest of the slide notes build on and can quickly explain each slide to the ambassador. It was found that these outcomes are needed in order to show the ambassador the exact purpose of every slide in the presentation.

Example Script

The example script is a dialogue that presents the ambassador with one possible way to explain the aforementioned objectives. They are a set of student instructions, explanations, and suggested questions in conversational form. The information is in quotation marks (“”). Our liaisons Kate Myers and Lauren Hillier particularly requested this example script during a weekly meeting and have used it in previous activities. This example script is designed to be flexible, allowing ambassadors to make adjustments to the presentation while ensuring that they understand the objectives that are meant to be communicated to the students.

It was found that providing a script for the ambassadors helps ease the amount of presentation preparation required, and can also improve ambassador confidence by eliminating the need to develop their own script for the presentation. In an example script suggestions and optional resources are preferred over rigid instruction to avoid stifling the ambassador; it could even be used as a basis for them to write their own script (H. McPherson, personal communication, March 25, 2014).

Also, if the ambassador is a STEM ambassador, or an expert in the activity’s highlighted STEM field, he or she may wish to modify the slide and script to incorporate his or her own experiences, allowing for more engagement in the activity for all parties.

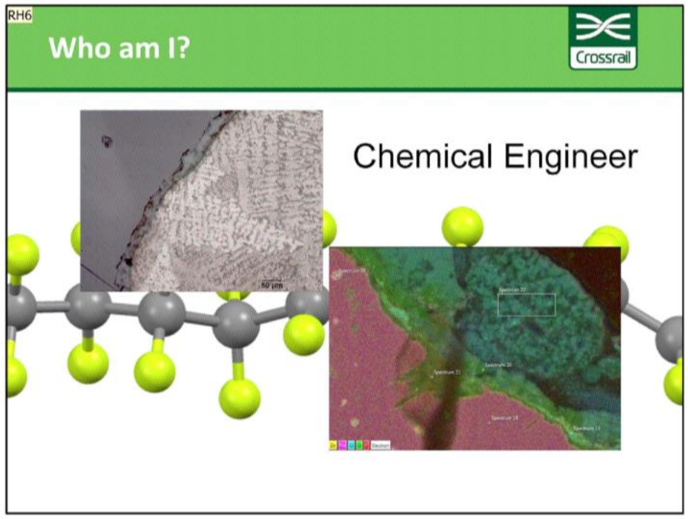
Supplemental Information

Any supplemental information for ambassador’s usage will be italicized at the end of the lecture notes for each slide. Supplemental information will include links to articles and webpages that further describe or explain material on the slides. YouTube video links may also be included in this section to help better explain certain concepts, and may also be used during the presentation (if time permits) to help explain concepts to students. These links and other bits of information are meant to ease the amount of research ambassadors would have to do if they still had questions regarding the presentation material, providing further background information to help boost confidence levels and improve the learning quality of the presentation.

Slide 3

Slide 3, at right, in every presentation, containing information for the ambassador introduction.

PowerPoint notes, below, for Slide 3 with objectives in bold, an example script in quotations, and additional commentary in italics.



Customize this slide to fit your personal details

Your introduction and profession
What is your job title?
What do you do for work/who do you work with?
What is your educational and professional background?
You are a real person, just like them! Share a challenge you've overcome to get where you are now or ask them if they share any of your favorite hobbies

"Right now I'm a student back in the States where I'm studying chemical engineering. In particular, chemical engineers can do a lot of things but I'm interested in materials. So what you'll see here is some of my work from last summer where I studied corrosion, or rust, of brass. In these pictures the outside rusted layer is different from the inside of the material, as shown by different colours pink and green."
"When I was your age, I wanted to be a science teacher. So while I knew I liked things like science, I had no idea where I would end up. Some of my favourite classes were chemistry and biology, do any of you like those classes too? I knew I didn't want to work in a lab so I wanted something a little different than just studying science that would help me work more with people When I was around 16 I figured out I wanted to be an engineer and I went to university where I am now."
"In my free time when I'm not in class, I like to garden and I work at my school's greenhouse. Do any of you have gardens at home? What do you grow?"

This slide has many objectives. Some of them may stand out to you as more important than others. Remember that you have a strict time constraint, so try to include as much information as you can, but mind the time limit.

Slide 3 gives ambassadors a chance to introduce themselves as the beginning of the presentation and capture the audience's attention. Slides such as this have been used in previous

Young Crossrail presentations and are valuable because they let the ambassador present their own pictures, details about their past, and a bit of their personality ("My Career Journey YC Template," 2014). As has also been indicated by research, the ambassador's personality is an important input in the presentation and should be augmented as early as possible (S. Miller, personal communication, April 2, 2014).This slide strategically asks the ambassador to present specific information about themselves, which is why it has more objectives than other slides.

What is your educational and professional background?

This objective addresses the ambassador's personal experiences. If the ambassador is a STEM ambassador, it will provide students with information on how to get involved in these careers, i.e. which GCSEs to take and what they need to do after graduating from secondary school. This has been identified as a problem area through preliminary research and interviews; students do not understand how to become an engineer (H. McPherson, personal communication, March 25, 2014). By showing them a real life example, they are able to see that it is doable and are given a potential pathway to puruse. It is also an excellent example for the ambassador to reflect on where they were in life at the age of the audience, which will draw in their attention.

Furthermore, research has shown that schools present life after secondary school as a linear progression of one career path. This makes students think they are restricted to one area of study forever (H. Cox, personal communication, March 21, 2014). In some cases this is correct, but in many it is not. In our interactions with ambassadors, they frequently change disciplines within STEM and even venture into entirely new fields. By showing students an ambassador career track, which may or may not be linear, students will see that their futures are more flexible and will feel less pressure about making important decisions now.

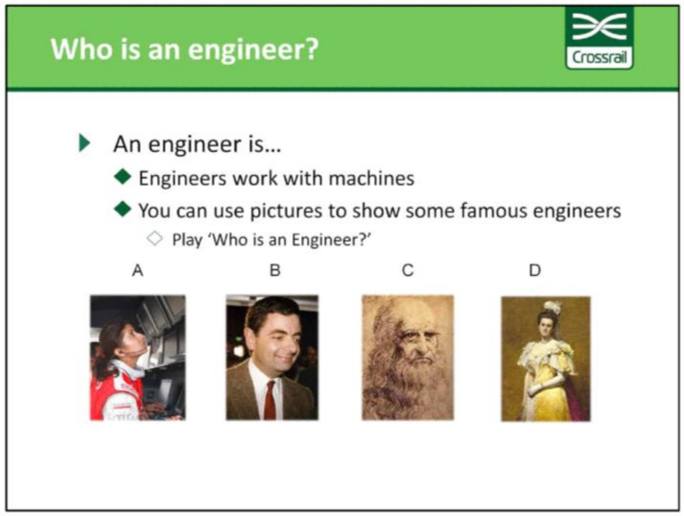
You are a real person, just like them! Share a challenge you've overcome to get where you are now or ask them if they share any of your favorite hobbies

Our research also indicated that current STEM outreach presents engineering as an elitist field that makes engineers into superhero-like figures (Karatas et al., 2011). This common misconception can be dispelled by presenting some personal information about the ambassador. It will allow them to bond with their audience, showing students that engineers are regular people too who once were faced with the exact same challenges the students themselves face.

Slide 4

Slide 4, at right, in the PowerPoint Introduction, containing information about engineers for students

PowerPoint notes, below, for slide 4



You can edit this activity as you wish to better fit your interests, as long as the people you talk about have engineering degrees or backgrounds, regardless of their better-known professions (Ex: Actor Ashton Kutcher has a degree in Biomedical Engineering). Remember to include engineers of both genders

Engage your audience early in the presentation.
Engineers come in all shapes and sizes, both men and women.

"Now that you have seen that I am an engineer, what types of people are engineers anyhow? In the pictures here, which of these people do you think are engineers?"
"In reality, though, they're all engineers. Leena Gade on the left is a race engineer. Rowan Atkinson, the actor who played Mr. Bean, has degrees in electrical engineering. Leonardo da Vinci was an engineer of his time, filling entire notebooks worth of inventions; and last, Emily Warren Roebling became an engineer to replace her husband in the building of the Brooklyn Bridge in New York City."

Engage your audience early in the presentation.

Preliminary research indicated that the best way for students to learn effectively about STEM is to teach it interactively (Tomlinson, 1999). When this matter was considered during Young Crossrail interviews, some ambassadors expressed concern that many existing activities similar to our programme lack advice on running the activity in a way that engages their student audience (L. Highe, personal communication, April 1, 2014). To approach this problem we considered how the programme is structured and how the programme is delivered to the students.

Slide 4, above was designed as a game for the ambassadors to engage students as early as possible in the presentation. The idea was taken from an early site visit to the Elizabeth Garret Anderson School where ambassadors called the game "Who is an engineer?" (H. McPherson, personal communication, March 25, 2014). Students are asked to consider which of the pictured famous people are engineers. They are able to brainstorm, discuss with their peers, and volunteer suggestions out loud. A detailed script in the notes is provided to guide the ambassador should they find it difficult to begin or explain this game, addressing the concern that there is not enough guidance provided to ambassadors in explaining audience engagement principles.

Engineers come in all shapes and sizes, both men and women.

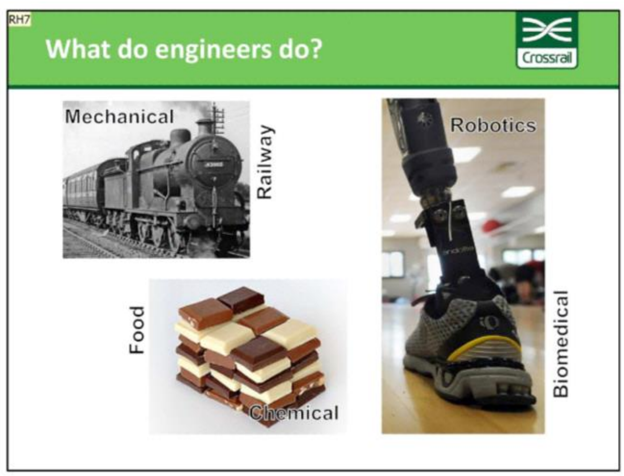
In many cases Young Crossrail will have no notice to the demographic of their student audience but still want to deliver messages to certain demographics in attempts to address the lack of female engineers. To approach this concern, embedded messages should be used in the presentation to avoid tailoring activities towards specific groups but to still target relevant parties (S. McElroy, personal communication, March 20, 2014).

While it is rare that a classroom will be made up entirely of female students, parts of the presentation which address female engineers were included in every presentation because a significant amount of female students would receive the message each presentation. In particular the engineering game on slide 4 shows all audiences that both females and males are engineers. The game provides four examples of engineers and is an excellent example to show successful men and women working side by side in a variety of engineering fields.

Slide 5

Slide 5 in the PowerPoint Introduction, at right, containing information about the types of engineering

PowerPoint notes for slide 5, below



There are animations on this slide correlating to the progression of the script
This slide is also customizable to your own preferences on pictures, information, etc.

What do engineers do?
Engineers solve problems
There are a variety of engineering disciplines
These disciplines all work together
Engineers do these things to help people

"Engineers have a variety of professions, from mechanical to environmental to biomedical…
Engage your audience: "In the picture on the above right with the prosthetic leg, how are they helping people?" (improved/restored mobility)

Preliminary research and ambassador interactions have shown that students have a poor understanding of the responsibilities of professional engineers when they are thinking about career paths earlier in their education. Furthermore, they also believe many misconceptions about engineers and engineering as a profession (Karatas et al., 2011; C. M. Cunningham, Lachapelle, & Lindgren-Streicher, 2005). This leads to universities in the United Kingdom experiencing a high turnover rate within engineering due to the misinformation about engineering careers (S. McElroy, personal communication, March 20, 2014), To address this problem and correct misconceptions, slide 5 looks at various aspects of engineering, including what engineers do, what different kinds of engineering exist, and how these people work together. The objectives on this slide were chosen to strategically present engineers as people who helping others, finding answers to problems, and people who are necessary to society (Messages, 2008).

In addition, on this slide and throughout the rest of the presentation, there are notes labelled as "engage your audience." These tips encourage ambassadors to interact with their audience via questions in order to hold their attention and maximize the impact of the programme. Preliminary research and interviews suggested that engineers as ambassadors need help presenting in this area because at times engineers are prone to "dumping information" rather than interacting with the audience, which is why this engagement issue is emphasized throughout the presentation (Cyr, 2014).

5.2.2 Ambassador Guide

The second document included in each programme package is the Ambassador Guide. Each Ambassador Guide is tailored towards an individual activity, while following a general format set up for all guides across the programme package. This format is broken into three sections:

1. Activity Information
2. Activity Instruction
3. Frequently Asked Questions

While the Ambassador Presentation provides the bulk of the information and defines the flow of the programme, the Ambassador Guide acts as an effective supplement that provides necessary information pertaining to the execution of each activity. It provides brief but specific solutions to any concerns and questions that the ambassadors may have about conducting the programme, and provides logistical information about each programme session.

When providing feedback about what they needed and what they saw useful in initial drafts of package documents, Young Crossrail ambassadors identified that they would like a specific guide through the activity that is easy to understand and quick to use (K. El-Hakim, personal communication, April 2, 2014). In response to this the Ambassador Guide was designed to be easily accessed by ambassadors, containing short, useful information sections that ambassadors can quickly refer to before and during the programme and still gain any information necessary for the preparation and execution of the activity.

Each Ambassador Guide contains three major elements which are designed to directly guide the ambassador through the programme with emphasis on the activity. These elements are Activity Information, Activity Instruction, and Frequently Asked Questions. Below, we have provided a description of each portion of the Ambassador Guide, with the rationale and analysis that led to its structure. Although each activity has its own unique elements and different steps, this shows the overall structure that each ambassador guide follows. For a more precise look at the information that relates to each individual activity and how they fit into this described structure, please refer to our actual programme packages in the appendices.

Activity Information

The Ambassador Guide begins with the Activity Information section with general information about each programme. This section essentially acts as a cover sheet that can be quickly referred to by our Ambassadors and our liaisons at Young Crossrail to identify the nature of each programme and the activity involved. It includes a list of required resources, required materials, related subjects, suggested group size, and an estimated time table.

Resources needed

This is a description of any resources required to conduct the activity, such as projection tools, or space to conduct the activity. Although our immediate range of activities do not require more than projection tools and tables for crafts, once further activities with more complicated settings are introduced, this information will allow ambassadors to know what to expect. Existing Activity information sheets in the Young Crossrail U Drive demonstrated this principle, and the report from the Science Museum IQP identified that teaching resources needed to provide this information for the educator’s convenience and understanding ("The Science Museum: Classroom Resources," 2014). We believed that this allowed ambassadors to be aware of what kind of location, space, and presentation tools are required to run each programme.

Suggested Student Group Size

This is the ideal group size the activity. Each activity has different suggested group sizes depending on its format and complexity, and it is useful for the ambassador to be aware of this number when dividing students into groups for the activity.

Materials Needed

This is a material list with specific numbers that the ambassador can check to prepare for each activity. Past Young Crossrail activity programmes had already utilized this, and Kate Myers, our liaison, also emphasized this among a list of essential information she requested to be provided in the document. It is important to note that this material list will expand from the information that students will receive to consider spare materials. An optional box of chocolates was also suggested as a prize that motivates students to be engaged. This was taken from a method that we observed at an educational session conducted at one of the partner schools, where the ambassadors encouraged participation by awarding engaged students with chocolate (H. McPherson, personal communication, March 25, 2014).

Related Subjects

This shows the key STEM disciplines that relate to the activity involved in the programme. This information helps both our ambassadors and liaison in identifying what subjects relate to the activity, and allows them to find an activity that fits their needs.

Total Estimated Time

This provides the total running time required for the programme to be conducted, including an approximate timetable for each step of the programme that has been devised as a result of continuous testing and review. It is essential that the ambassador keep track of time during the progression of the programme, and be aware of what steps they will run through when conducting the program. Because it provides a specific plan that complements the plan of the programme defined in the Ambassador Presentation, this timetable becomes ones of the most important elements of the Ambassador Guide.

Activity Instruction

This portion of the Ambassador Guide provides suggestions and guidelines specifically structured towards the activity. It explains the necessary steps that ambassadors should keep in mind and follow throughout conducting the programme.

When collecting feedback about the programme package from the ambassadors and our liaisons during the Ambassador Mixer, they showed a general preference to have a reference sheet that could be easily accessed. However, they did not want an extensive document that contained all the information that they needed for the programme. As a result, more extensive information was included in the PowerPoint, making it the main resource for the ambassadors, while this section of the Ambassador Guide became a checklist of instructions to remind the ambassador of any necessary steps and considerations they should keep in mind for the programme.

Naturally, Activity Instruction is different for each Activity, but follows a general structure to ensure that documents created for the activities are standardized and easy to replicate.

Reminders on how to prepare for the programme session and any necessary tasks are first stated to give ambassadors assistance with running the programme from preparation to clean up. These included ambassadors checking for materials beforehand, setting up things once they arrive, and collecting materials after each programme session.

A section of **requirements and restrictions** of each activity is also provided, mirrored from the Student Activity Sheet. This portion discusses which materials the students are given, and what they are asked to accomplish in the activity. This was placed here for the ambassadors to conveniently access information while the activity is being conducted, touching on the concept of the materials being easy to use for the Ambassador. This will also contribute to student engagement in the activity, as students will better understand the requirements of the activity by asking the ambassador when necessary.

The final section focuses on the **organization** of the activity, and provides suggestions and reminders for the ambassador to cover all the necessary objectives of the activity, and to keep track of time. This once again comes from our findings of ambassadors requiring instruction to easily conduct the activity with the information we provide.

Frequently Asked Questions

The Frequently Asked Questions are a combination of activity specific tips and general programme implementation tips that are provided as solutions that the ambassadors can refer to if any problems or issues are observed with students in the implementation of the activity, or engagement in the programme in general.

Each of the activity tips, devised specifically for each activity, are based on findings from actually testing the materials for the activity, and observing issues with implementing an activity that could occur when students try them out. The tips give suggestions to various situations such as students failing to implement a required product, or being unable to come up with a given design for the task. Ambassadors are given suggestions to refer to STEM backgrounds provided in the Ambassador Presentation, or examples of working products, etc.

This necessity of this element essentially originated from the challenges that are involved with each activity, and considerations for the differing capabilities among students relating to the adaptability criteria that were identified through our findings. In our interviews, ambassadors identified that students vary in engagement levels and ability, meaning that some students may struggle with the tasks they are given (L. Highe, personal communication, April 1, 2014). This set of tips allows students with different levels of understanding to be equally engaged in the activity.

These activity tips also direct ambassadors to reinforce engineering principles in the students' approaches to activity solutions. The ambassadors are asked to encourage students through designing, building, and testing their products, so that they learn the process of engineering and problem solving, instead of being given direct help, or a fixed solution.

The presentation and discussion tips were primarily based on feedback collected from ambassadors, while also integrating observations made by the project group at visits to presentations at schools. These tips were fast solutions and suggestions to address disruptive behaviour, student disinterest, or a lack of participation during the programme implementation. Strategies to engage students and motivate them to ask questions and actively participate in discussion were based on engagement strategies that were identified in out background research of the Science Museum's educational resources ("The Science Museum: Classroom Resources," 2014).

For more information on the Frequently Asked Questions section, please see the Appendices.

5.2.3: Student Activity Sheet

Student activity sheets are worksheets that are handed out to the students when each programme is conducted. This document will include information for students including but not limited to a list of materials, timing, and instructions. Ambassadors can refer to this document during their activity presentation slides and students will have a clear idea of what the activity requires after reading the document.

Student activity sheets are meant to help facilitate the activity and not stifle it. To avoid such problems, a minimalistic approach was taken in developing student activity sheets to avoid excessive details. This would prevent students from becoming overwhelmed with information that would ultimately inhibit the experience (L. Highe, personal communication, April 1, 2014).

Diagrams were also a major part of the student manual because it is the first item students notice. Diagrams had to be simple and directly remind students of the STEM background of the presentation that preceded the activity. As a result of an ambassador focus group, extra details in the diagram were carefully avoided to ensure students would not be confused or misled (L. Highe, personal communication, April 1, 2014).

Content in the student activity sheets vary between different activities, as different activities have different implementation methods and therefore need different kinds of instructions and activity/subject descriptions. A fixed structure that was followed was the inclusion of a material list, a task description, and discussion prompting questions.

The material lists included a list of what materials the students were going to be provided with for each activity. If the programme is being hosted as part of a Young Crossrail event, these materials will be provided by Young Crossrail. If not, these materials will have to be assembled at home by parents and students. As such, the materials list is written to indicate what the material is without making families at home feel that the activity is undoable because they don’t have that exact item (R. Cox, personal communication, April 4, 2014). This promoted further student engagement in creative activities even after the programme is finished.

The task description was essential information that performed as a reference to the activity the students were going to be doing, and what kind of requirements or restrictions it had.

Discussion prompting questions were used to explicitly state the objectives of the activity for the students to see. These would also guide the discussions that would follow each activity. Such discussion questions were identified as a strong point by ambassadors involved in the First Lego League activities because they reflect real world interdisciplinary responsibilities of engineers (K. El-Hakim, S. Miller, personal communication, April 2, 2014).

Appendices

Appendix A: National Curriculum Standards

The National Curriculum mandates minimum curriculum standards for each Key Stage of formal education in the United Kingdom. Key Stages are age brackets within the student population and are outlined in the table below:

Table 6: Key Stage Structure

Key Stage 1	Ages 5-7	Years 1 and 2
Key Stage 2	Ages 7-11	Years 3 to 6
Key Stage 3	Ages 11-14	Years 7 to 9
Key Stage 4	Ages 14-16	Years 10 and 11

The primary audience of our Young Crossrail lessons is Key Stage 3. Key Stage 2 information has been included in this appendix in addition to Key Stage 3 information as a foundation for what students are expected to know coming into a Young Crossrail lesson. Since these lessons give students the opportunity to focus their attention on specific STEM subjects, it is prudent to list only the necessary related school subjects in this appendix.

Forces and Motion

Key Stage 2:

- That objects are pulled downwards because of the gravitational attraction between them and the Earth
- About friction, including air resistance, as a force that slows moving objects and may prevent objects from starting to move
- That when objects [for example, a spring, a table]are pushed or pulled, an opposing pull or push can be felt
- How to measure forces and identify the direction in which they act.

Key Stage 3:

- How to determine the speed of a moving object and to use the quantitative relationship between speed, distance and time
- That the weight of an object on Earth is the result of the gravitational attraction between its mass and that of the Earth
- That unbalanced forces change the speed or direction of movement of objects and that

balanced forces produce no change in the movement of an object

- Ways in which frictional forces, including air resistance, affect motion [for example, streamlining cars, friction between tyre and road]
- That forces can cause objects to turn about a pivot
- The principle of moments and its application to situations involving one pivot
- The quantitative relationship between force, area and pressure and its application [for example, the use of skis and snowboards, the effect of sharp blades, hydraulic brakes].

These standards are taken directly from the National Curriculum website.

Appendix B: Stake holder interviewees

Name	Job Title	Stakeholder Category
Cox, Hannah	Education Officer of the Royal Festival Hall	Educator
Cox, Roger	Head of Engineering Crossrail	Active Ambassador, Engineer
Donovan, Ian	Vocational Coordinator of Rokeby Preparatory School	Educator
El-Hakim, Khouloud	MEP Package Manager	Active Ambassador, Engineer
Highe, Lih- Ling	MEP Package Manager	Active Ambassador, Educator, Engineer
Heaton- Renshaw, Archie	Delivery	Active Ambassador, Engineer
McElroy, Susan	Assistant Project Manager- Station Hub	Active Ambassador, Engineer
McGeary, Damien	Construction Teacher of Royal Greenwich University Technical Center	Educator
McIntyre, Martin	Construction Manager	Engineer
McPherson, Heather	Interface Manager	Active Ambassador, Educator, Engineer
Miles, Geoff	Depots Manager	Engineer
Miller, Simon	Simon Miller	Active Ambassador, Engineer
Purcell, Gregg	Construction Manager	Active Ambassador, Engineer
Shad, Ali	Hub Graduate	Active Ambassador, Engineer
Thomas, Colin	Engineering Manager	Active Ambassador, Engineer

Appendix C: Clockwork Challenge Programme Package

Ambassador Guide

Activity Title: Clockwork Challenge

Resources needed:

Screen and Projector for Ambassador Presentation

Classroom with tables/desks for students to work as groups

Suggested Student Group Size:

3-5

Materials needed Per Group:

Pens/Pencils

Paper

LEGO kit

****Optional materials****

A box of Chocolates or Candy is suggested as prizes.

Related subjects:

Applied Maths, Team Problem-Solving

Documents included:

Ambassador Activity Guide,

Power Point Presentation

Student Worksheet

Evaluation Form

Total Estimated Time: 1 hour 30 minutes

Activity	Time (mins.)	Slides
1. Introduce Crossrail and Engineering	10	1-8
2. STEM Background	5	9-10
3. Team Formation	5	11
3. Project Explanation	5	11-14
5. Planning work	35	14
6. “Incidents”	5	14
7. Presenting	5	15-16
8. Discussion and Activity Evaluation	20	17-18
Total:	**90**	**18**

This Ambassador Guide is designed specifically for the **Clockwork Challenge** activity. It includes general information about the activity, and tips on how the included activity could be best implemented. Please use this guide with the Ambassador Presentation to effectively conduct the programme. It will follow the progression of the PowerPoint.

Before the Classroom Checklist ☑

- ☐ Get in contact with Young Crossrail (youngcrossrail@crossrail.co.uk) to ensure that you have the kits/ materials needed to present the lesson
- ☐ Review and customize the PowerPoint to your liking.

Activity Instructions

Instructions

1. Divide students into groups of 3-5, 4 being an optimal number
2. Give each group their designated materials
3. Thoroughly explain the requirements of the activity
4. Let the students create their plans
5. Administer 'incidents and delays' (see below)
6. Collect materials at the end of a discussion and team presentation period
7. Hand out evaluation forms

Requirements and Restrictions

Keep in mind when assisting students:

- Electricians can only work a maximum of 10 days with a minimum 5 day rest period between each 10 day block
- Flooring and Glass work cannot be completed simultaneously
- Heating and Air Conditioning must be complete before Flooring can be started
- Only 3 tasks can be worked on at one time
- "Double up" work is not allowed
    - The same task cannot be placed in more than one row/column concurrently.

Organization

Keep track of time during the activity. An estimated running time is as follows

Phase	Time (mins.)
Team Formation	5
Explanation	5
Activity/Incidents	45

There is no testing phase for this activity, but each team will be asked to tell how many days they could complete construction in.

Incidents

To add another layer of complexity to the challenge, you can add some plot twists to the activity. After the 35 minutes are up, have the groups stop work on their schedule.

- Tell the group something like 'There has been an accident on site 45 days into construction!' causing a stoppage of work for 5 days as the incident is investigated' or 'There is a plumber's union strike 30 days into construction, meaning that no plumbing work can be done for 10 days, and allow them to adjust their total number of days to completion.
- **Students may not rearrange their schedules prior to the day the incident happened (just like you can't turn back time in real life), but may rearrange their schedules after the start of the incident**.
- Limit the number of 'incidents' to 2-3. Be creative, but realistic if you choose to make your own "incidents", and keep the delays in 5 day increments (i.e. 5, 10, or 15 day delays).
- Don't make the delay too long as the students will only have room for 150 days on their schedules. Also, try not to exceed 15-20 days worth of "incidents" as the minimum number of days to completion is 110 days, leaving 15 days of freedom before going over goal.

After the Lesson

Ensure that all the materials have been returned by completing the check list in each kit.

Activity Tips

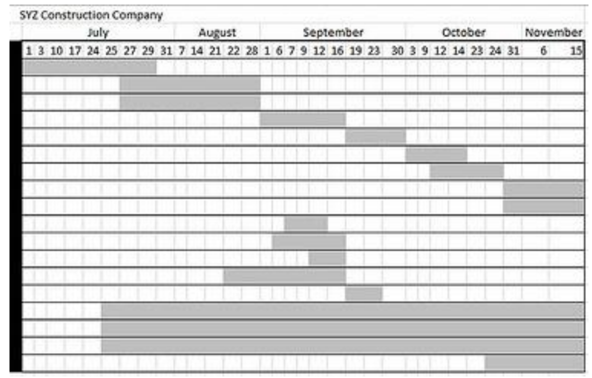
Q: What if students are struggling to understand the task or relevant information?
A: Have them write down the key points, including the number of days to complete each task, what color each task is, and any restrictions on specific tasks that may exist. If they're still struggling after they write down the critical information, have them start placing LEGOs on a board to visualize a schedule. They should be able to work from this point.

Q: What if students are frustrated because they can't get their schedules under goal before incidents are implemented?
A: Check to see if all of the tasks are blocked together. In order to get under the goal, they will need to divide some tasks up and not leave empty spaces on the board. As long as the tasks don't overlap once divided (take up the same block of time in more than one task row/column), they are following the rules.

Q: What if students are struggling to understand the "incident assessment" or the restrictions about schedule rearrangement during the "incidents"?
A: Explain to them that in real life, you can't go back in time. Once you start implementing "incidents", it is as if construction has started on the project according to their plans, and the schedule can only be rearranged after the day something happens.

Q: What if students are frustrated because they can't meet the goal after "incidents" happen?
A: Explain that in real life, things happen and force you to be delayed beyond your ability to meet a deadline.

The Clockwork Challenge



Example Schedule

You will need:

- Paper
- Pens/Pencils
- Lego Kit

Time: 35 minutes

Team

Your team will include 4 members of your class

Objective

You are a project management team responsible for the construction of a new railway station. Your team will organize all of the subcontractors (other companies helping with the construction project) in a way that will get the station built in the least amount of time. Your goal is to finish construction in **125 days**. The team who finishes in the fewest number of days wins!!!

Instructions

- Use the LEGOs to create your “plan”
- **1 LEGO Brick = 5 days**

Specifications

- You may use the LEGOS in any way you want to create your “plan”, as long as you can show that **no more than 3 tasks being done at one time**.
- You must complete **6 tasks:**

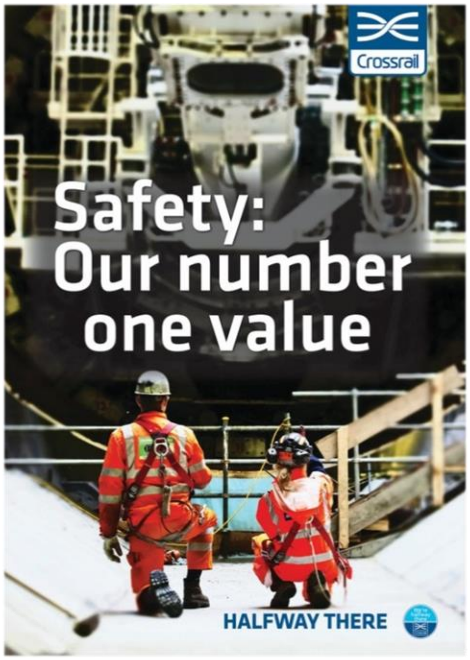
Task (LEGO Colour)	Days to Complete	Other Restrictions
Electrics (Orange)	40 days	5 day inspection after every 10 days worked. All other tasks can proceed during the inspection period.
Plumbing (Blue)	10 days	None
Flooring (Pink)	50 days	Cannot start without finishing Heating and Air Conditioning, and cannot when Glass Work is being done because the Floors and Glass are being installed by the same contractor
Glass Work (Yellow)	30 days	Cannot be done at the same time as Flooring because the Flooring and Glass Work are being done by the same company
Heating and Air Conditioning (Tan)	35 days	Must be finished before Flooring can be started due to Health & Safety concerns
Brick work (Red)	100 days	None

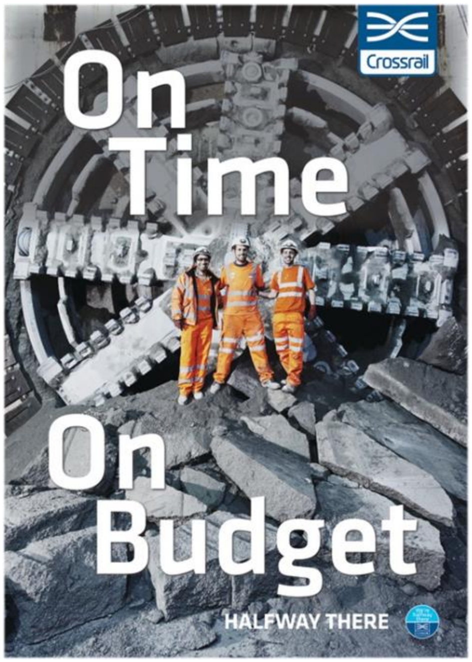
Background Information

Right now on the Crossrail project, the main focus is moving towards station construction. Tunnelling is scheduled to be complete by the end of 2014, and as tunnel construction is coming to an end, station construction has just been getting started. With 40 stations along the Crossrail route, including 10 brand new ones, the refurbishment and construction of stations along the Crossrail route is critical because without stations, people won't be able to use the incredible new rail service.

Every station construction contract must be managed by a project management team. This team of managers is responsible for:

- Everyone's safety at the construction site
- Making sure construction is on schedule
- Making sure construction is within budget (doesn't cost too much)





Appendix D: Station Creation Programme Package

Ambassador Guide

Activity Title: Station Creation

Resources needed:
Screen and projector for Presentation
Enough Table space for crafts, accommodating the class size

Suggested Student Team Size:
4 – 6 (aim for 4 groups per class/group)

Materials needed Per Group:
150 toothpicks
380 grams of Jelly Babies (2 small packages)
5 sheets of white A4 paper

****Optional materials****
A box of Chocolates or Candy is suggested as prizes.

Related subjects:
Architecture, Civil/Architectural Engineering

Documents included:
Ambassador Lesson Guide,
Power Point Presentation
Student Worksheet
Evaluation Form

Total Estimated Time: 1 hour 30 minutes

Activity	Time (min)	Slides
1. Introduce Crossrail and Engineering	10	1-7
2. STEM Background	5	7-12
3. Project Explanation	5	13-16
4. Project Brainstorming/ Planning	10	16
5. Building	40	16
6. Testing /Presenting	15	17-18
7. Feedback and Discussion	5	19-20
Total:	**90**	**20**

This Ambassador Guide is designed specifically for the **Station Creation** activity. It includes information for the activity, and tips on how it could be best implemented. Please use this guide with the Ambassador Presentation to effectively conduct the programme.

Before the Classroom

- Get in contact with Young Crossrail (youngcrossrail@crossrail.co.uk) to ensure that you have the kits/ materials needed to present the lesson
- Review and customize the PowerPoint to your liking

In the Classroom

- Make sure you have the sets of materials readily divided into the appropriate number of student groups.

Activity Instructions

Instructions

8. Divide students into 4 teams (cap the team size at 6 students)
9. Give each group their designated materials
10. Thoroughly explain the requirements of the activity.
11. Let the students plan and build their stations.
12. Let students present their “stations”.
13. Collect materials at the end of a discussion and team presentation period
14. Hand out evaluation forms

Requirements and Restrictions

There are minimal restrictions to this activity. The primary restrictions are:

- 50 minute time limit (10 mins brainstorm in teams, 40 mins build)
- Minimum station floor dimensions: 1 sheet of A4 paper
- Maximum station floor dimensions: 3 sheets of A4 paper, touching lengthwise
- Station must have minimum two levels (Ground plus at least one upper level)
- Limited amount of materials
- The structure must be freestanding and capable of supporting 0.5k g on its 1st “floor”

Organization

Keep track of time during the activity. An estimated running time is as follows

Phase	Time (mins.)
Team Formation & Task Explanation	5
Team Construction	50
Presentation/Testing	15

Testing for this activity involves checking the dimensions of the station to make sure that it is within the maximum and minimum dimensions. Also, the structure must be able to support 0.5 g (5x100g weights) on its 1^{st} “floor”. Presentation involves a 2-3 minute “elevator pitch” of why the team chose its particular statin design.

After the Lesson

Ensure that all the materials have been returned by completing the check list in each kit.

Activity Tips

Q: What if students are struggling to understand the task or relevant information?
A: Explain to them that they need to sketch a design for their station, and then use the given materials to build the station they design. Each student should have an assigned task to focus on, dividing labour, just as it would be done in real life.

Q: What if a student’s design doesn’t work?
A: Just as in real life, designs may not work. Explain to them that they have to go back and rethink or redesign the station or elements of it before continuing construction. This redesign process may end up as a discussion topic during the group discussion.

Q: What if students are struggling to design a structure that will stand on its own or function?
A: Remind the students that, just like materials, sometimes structures need reinforcement. Building cross-braces or using certain geometries like triangles can help to give their structures more strength, just as materials are added to steel and concrete to increase their strength.

Presentation Tips

Q: What if I have a class of unmotivated and unengaged students?
A: Make the session relevant to their day to day lives. By connecting the lesson to real- world experiences they will not feel like they are learning for the sake of GSCEs. Start by asking them what they like to do outside of school, what they want to do when they graduate and draw a link to how maths and sciences could help them then.

Q: How do I make sure students get the most out of the activity?
A: Ask students to justify their actions and decisions as the activity progresses. To avoid singling out students who may be shy, pose the question to a group so that as many who want to answer will while quieter students would still be able to contribute to the answers.

Q: How do I deal with disruptive behaviour in the classroom?
A: Remember that you are not the only responsible adult in the classroom and that there are full time teachers to help oversee the students. Ask the student for a reason behind the misbehaviour and if there is anything that you can do to help such as offering a different seating arrangement.

Station Creation

You will need:

Toothpicks (150)
Jelly Babies (2 bags, 190g each)
Paper (5 A4 sheets)

Time: 50 minutes total

10 minutes: team brainstorm
40 minutes: build

Team

Your team will include you and 3-5 of your classmates.

Objective

Design and build a model of a new railway station as seen from the street. Assume that the train enters the station underground, just as it will at the on the Crossrail line through central London.

Instructions

There are four roles in each team:

Architects – who will design the station's layout and appearance (1 or 2 per team)
Field/Structural Engineers – who will work on the structure's design (1 or 2 per team)
Site Managers – who will make sure construction is on schedule (1 per team!)
Project managers – who make sure that the others complete their tasks on time and create, introduce, and close the presentations. (1 per team!)

Read next pages for your role descriptions. Be sure to communicate with each other.

Specifications

- Minimum station floor dimensions: 18 cm wide x 22 cm long
- Maximum station floor dimensions: 20 cm wide x 24 cm long
- Station must have minimum two levels (Ground plus at least one upper level)
- The structure must be freestanding and capable of supporting 500g on its 1st level

Class Discussion:

Your team will be required to prepare a 3 minute presentation for a class discussion after finishing the activity to explain your station's design and how you built it.

Background Information

Right now on the Crossrail project, the main focus is moving towards station construction. Tunneling is scheduled to be complete by the end of 2014, and as tunnel construction is coming to an end, station construction has just been getting started. With 40 stations on the Crossrail route, including 10 brand new ones requiring construction, the refurbishment and construction of stations along the Crossrail route is critical because without stations, how are people going to be able to use the incredible new rail service?

Every station that is being constructed starts with weeks or months of planning prior to dirt being moved. During this planning time,

- Architects design the building. What it looks like, where the doors are, where the escalators go, and other things related to building design.
- Engineers figure out how to build what the architects designed. They decide on what building materials to use and make sure the building will be safe for passengers to use.
- Crossrail engineers think about things like the need to handle hundreds of thousands of people per day, the need to be built to last for at least 100 years, and also be built so that there is minimal damage to any of the surrounding buildings, roads, rail lines, and sewers when planning how to build the new stations.
- Site Managers make sure construction work is going to plan and the designs and plans of both the architects and engineers are being followed.
- Project Managers are in charge of everybody working on the project. They make sure that everyone is doing their work and finishing on time, and makes sure that everyone is working safely.

Architects

Congratulations! The construction of a new station on the Crossrail line has been approved by the Sponsor Board. Your job is to design the new station.

- You must design a station (You need to create drawings of floor plans for the floors your team will be constructing, as well as 'elevation drawings' showing what the building will look like from the outside). It must have at least two floors, and must have a footprint width between 18 and 20 cm, and footprint length between 22 and 24 cm in order to be large enough to accommodate the passenger traffic through the station.

- You will need to explain your design during presentation. Questions to ask yourselves for the presentation are:
  1. Why did I design the station this way?
  2. Is it an appealing design (would you want to look at it or be inside it)?
  3. Is it easy to navigate/get around inside the station?
  4. Is it easy to build?

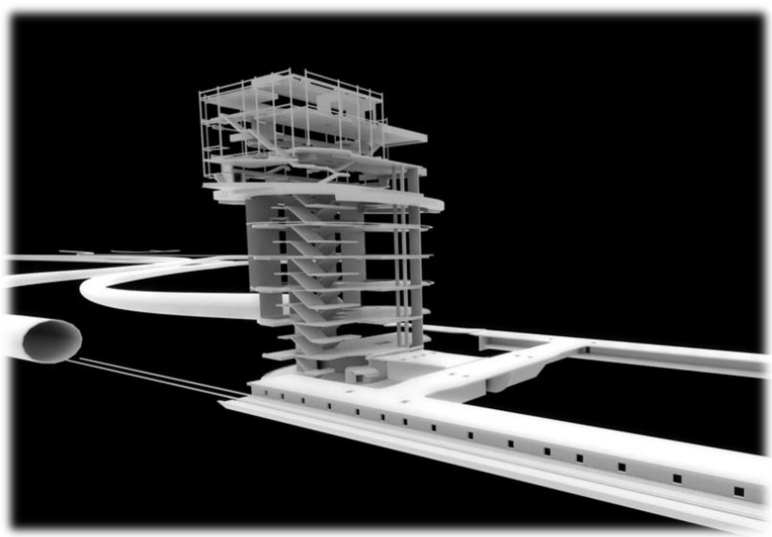
You have 10 minutes to work with the engineers and team to come up with your plan and then 40 minutes to help construct the model and create your presentation.

<u>You have the final say on the artistic design of the station!!!</u>

Good Luck!

Field/Structural Engineers

Congratulations! The construction of a new station on the Crossrail line has been approved by the Sponsor Board. Engineers need to help the architects design become a reality.



Your job is plan how to build the structure to look like what the architect's drawing, but also to be a freestanding structure that is functional. The materials have already been chose. Now it is your job to make sure that the structure meets the following requirements:

- Strength – Is the building sturdy? Can it stand on its own? Can it hold weight?
    - Think about geometry: What shapes are the strongest?
- Design – Does it follow the architects' design?
- Construction time – How easily can the structure be built? Can it stay within budget and meet the construction deadline?

You have 10 minutes to help the architects and team to come up with your plan and then 40 minutes to help construct the model and help to pull together the presentation.

<u>You have the ability to advise the architects against design elements if they are too difficult to build and call for a redesign of any part of the station at any time!!!</u>

Good luck!

Site Managers

Congratulations! The construction of a new station on the Crossrail line has been approved by the Sponsor Board. You are in charge of the construction site. You manage all material flow and ensure that all construction materials are being used with minimal waste. You are also in charge of making sure the construction is still on schedule and materials are available when needed to ensure on-time construction.

You will need to think about a number of factors when managing your site.

- Are all Health & Safety rules being followed?
- How many people are working on the construction site at any given time?
- Who is working on what, and when?
- Are there enough materials on site to finish each phase of the construction?
- Are materials arriving to the job site on time or do we have to place orders earlier?

You have 10 minutes to help provide design ideas for the architects and engineers, and then 40 minutes to lead the construction of your team's model.

<u>You have the power to stop construction at any time if you see problems or safety issues during the build process!!!</u>

Good luck!

Project Manager

Congratulations! The construction of a new station on the Crossrail line has been approved by the Sponsor Board. Your job is central to making sure that all tasks are completed and the presentation is produced to a high standard. You will also introduce and close the presentation. As in *The Apprentice*, the PM has final say!

The other members of your team have the following tasks:

- Architects – Design the station
- Engineers– Plan how to build the station's structure/framework
- Site Managers – Plan who will work on what parts of the construction phase

They will have **10 minutes** to come up with their plans and begin construction and it is your job to work with them and make sure that they complete construction in **40 minutes**.

You may provide design ideas to the architects and engineers, and may also assist in the construction of your team's model.

<u>**You are also responsible for creating, introducing, and ending your presentation. You decide how you want to present, but you must get information from all other employees on the project, and make sure your team finishes construction on time!!**</u>

Good luck!

Appendix E: Structure is Key Programme Package

Ambassador Guide

Activity Title: Structure is Key

Resources needed:
Screen for Presentation and explanation.
Enough Table space for crafts, accommodating the class size

Suggested Student Group Size:
3 - 4

Materials needed:
Weights (2kg total, 100g blocks x 20)
Two wooden Blocks (Can be substituted by two hardcover textbooks)

Materials needed Per Group:
Paper (40 precut eighth segments and 10 whole sheets)
Scissors
Masking Tape
Ruler

****Optional materials****
A box of Chocolates or Candy is suggested as prizes.

Related subjects:
Kinematic Physics, Material Science

Documents included:
Ambassador Guide
Ambassador PowerPoint
Student Activity Sheet
Evaluation Form

Total Estimated Time: 1 hour 30 minutes

Activity	Time (min)	Slides
1. Introduce Crossrail and Engineering	10	2-7
2. STEM Background	15	8-16
3. Introduce Activity	5	17-18
4. Activity Time	**40**	**19-20**
5. Discussion.	10	21-22
6. Presentation of design and Winner	10	23
7. Additional Activity	Additional Time	24
Total:	**90**	

This Ambassador Guide is designed specifically for the **Structure is Key** activity. It includes information for the activity, and tips on how it could be best implemented. Please use this guide with the Ambassador Presentation to effectively conduct the programme.

Before the Classroom Checklist ☑

- Get in contact with Young Crossrail (youngcrossrail@crossrail.co.uk) to ensure that you have the kits/ materials needed to present the lesson.
- Review and customize the PowerPoint to your liking.
- Make sure you have sheets of A4 paper cut into eighth segments.

In the Classroom

- Prepare piles each containing an A4 sheet cut into eighths ready to be distributed to students.

Activity Instructions

Instructions

1. Give each group their designated materials
2. Explain requirements of the activity.
3. Facilitate building and oversee student testing
4. Distribute materials for second groups to groups finished with first task
5. Initiate Testing Phase
6. Await students who require replacement materials or want to test.

Requirements and Restrictions

These are also noted on the student activity sheets. They are meant to encourage students to apply the STEM principles they've learned. Be aware of these when testing their structures.

First Task: Supporting Weight
Materials to Distribute: 8 Strips of paper (eighths of A4), Masking Tape, Scissors, and Ruler

- Students build a stable platform that can withstand 1kg of weights with the given materials.
- Platform must be **at least 8cm** tall,
- Platform must be **stable** and **free standing**

Second Task: Paper Bridge
Materials to Distribute: One sheet of A4 paper, Scissors, and Ruler

- The bridge must span a **15cm** gap without attaching to platforms
- When testing students may place weights on the bridge in any way they wish, as long as they are placed between the platforms and above the gap.

Organization

Keep track of time during the activity and closely monitor students' progress to ensure they are moving at an adequate pace

Phase	Time (min)
Explanation	5
First task	20
Second Task	20

There will be testing required for both tasks. Be aware of what order students came in and how much materials they are using.

After the Lesson

Ensure that all the materials have been returned by completing the check list in each kit.

Activity Tips

Q: What if the students are struggling to construct a platform or bridge?
A: Allow students to think about the issue. Ask them to remember what was covered in the presentation and give hints or reminders. If they are still struggling, show them a diagram or example picture from slides 8-13.

Q: My students have difficulty further improving their initial bridge design.
A: Explain that there is always a better way of solving the problem or making something better. Ask them to keep trying, and give a prize for each step of improvement.

Q: What if the students' designs don't work?
A: Sometimes things go wrong. It's important to show the students what worked in other cases and what didn't work in their case. Try asking what they could have done better and what they learned.

Structure is Key

Task One: Weight Support

You will need:
Paper (One A4 sheet divided into eighths)
Masking Tape
Scissors
Ruler

Time: 20 minutes total

Team
Your team will include 2-3 members of your class.

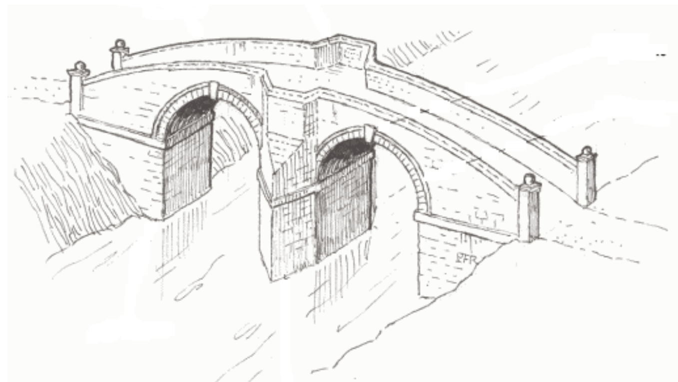
Objective
Build a stable platform that can withstand 1kg of weight with the given materials.

Instructions
Once your design is complete, bring the platform to the instructor for testing. If an attempt fails, you may attempt it again with a new set of paper after any other group has finished testing. DO NOT reuse any paper from the previous attempt. Once the structure succeeds, you will be allowed to move on to the second task.

Specifications
The platform should be:

- At least 8cm tall
- Stable and free standing, you should not have to hold it up!
- Able to support 1kg

<u>Task Two:</u> Paper Bridge



You will need:

Paper (One A4 sheet)
Scissors
Ruler

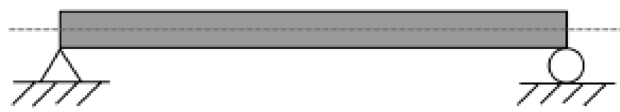
Time: 20 minutes total

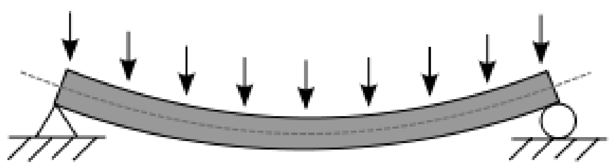
Team

Your team will include 2-3 members of your class.

Objective

Build a paper bridge between two platforms that supports as much weight as possible.





Instructions

- Once you think that your group is ready to test your bridge, ask the instructor for weights.
- Keep on trying different forms and designs. Consider the examples of structural design covered in class.

Specifications

- The bridge must span a 15cm gap without attaching it to platforms.
- You will be able to place weights on the bridge in any way you wish as long as they are placed between the platforms and above gap.

Appendix F: Train Design Programme Package

Ambassador Guide

Activity Title: Train Design

Resources needed:
Screen for Ambassador Presentation
Classroom with tables/desks for students to work as groups

Suggested Student Group Size:
2 - 3

Materials needed for Ambassador:
Railway kit (10 wooden rods, tape, example car)

Materials needed Per Group:
Masking Tape
Lollipop Sticks (15)
Dowel (2)
Spool (4)
Scissors
Paper Clips (6)
Wire (6 – around 20 cm each)
Ruler

****Optional materials****
A box of chocolates or candy is suggested as prizes.

Related subjects:
Railroad Engineering, Mechanical Engineering

Documents included:
Ambassador Activity Guide
Power Point Presentation
Student Worksheet
Evaluation Form

Total Estimated Time: 1 hour 30 minutes

Activity	Time (mins.)	Slides
1. Introduce Crossrail and Engineering	5	1-6
2. STEM Background	10	7-11
3. Project Explanation	5	12-14
4. Project Brainstorming/ Planning	10	14
5. Building	30	14
6. Testing	10	14
7. Group Run and Discussion	20	15-16
Total:	**90**	**19**

This Ambassador Guide is designed specifically for the **Train Design** activity. It includes information for the activity and tips on how it could be best implemented. Please use this guide with the Ambassador Presentation to effectively conduct the programme.

Before the Classroom Checklist ☑

- ☐ Get in contact with Young Crossrail (youngcrossrail@crossrail.co.uk) to ensure that you have the kits/ materials needed to present the lesson.
- ☐ Review and customize the PowerPoint to your liking.
- ☐ Practice setting up the railway you will have to assemble in the classroom. In the Railway Kit there will be 10 wooden rods and tape. These will make a rail around 3 meters long when they are set up on a slope. By taping the ends of the rods together you can make a rail for students train cars to run on, as shown in Figure A. When taping the rods together it's important that you wrap tape about 10 cm on each rod, as shown in Figure B. Three main considerations with the rail are width, stability, and incline.
    1. Be sure that the two pieces of the rail are equally spaced in a way that fits the model train car included in the railway kit. Students will have to build around this width.
    2. Be sure that the rail is supported (taped down) firmly on both ends and that the middle does not sag too much. Example pictures have been provided below to show you one good way to tape the end to the desk on a slope (Figures C,D, and E).
    3. When taping down the rail, tape one end to a chair and the other to the ground. You should test the model train car to ensure that the slope of the rail is adequate so that gravity will carry the car down the slope without stopping in the middle. This practice rail shown below is 0.5m tall. When cars reach the end they are moving pretty quickly and will continue to roll across the floor.

Figure A: Rail sloping from table to floor. Sloping to floor will ensure that rail cars do not derail at the end and break. Notice that the top of the rail is at a slope, not parallel with the table.

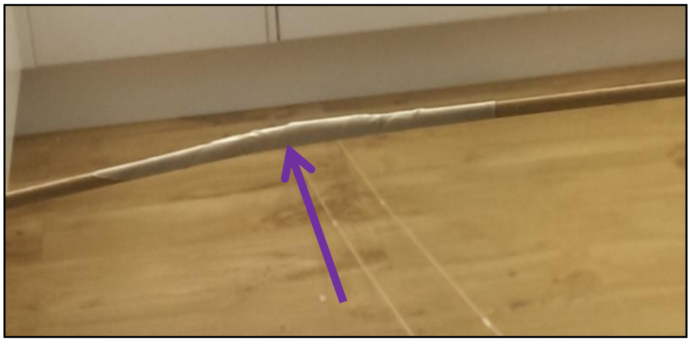
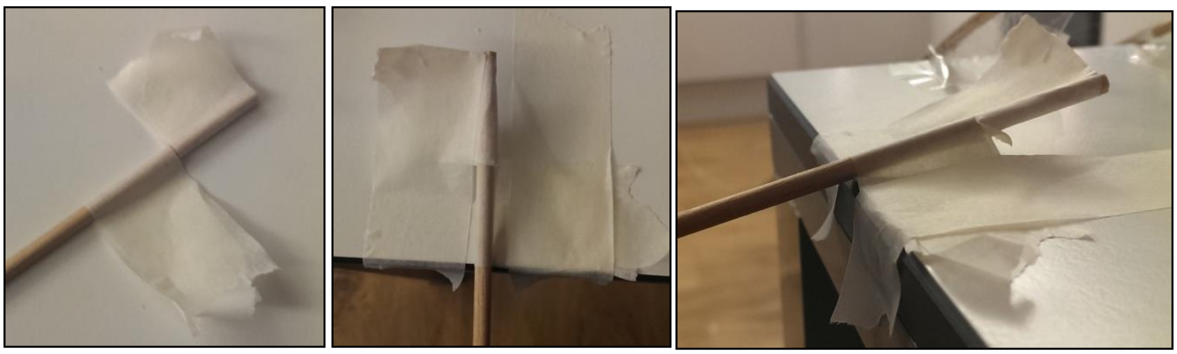


Figure B: The temptation will be to just tape where the joint is, but this won't work well. Apply tape liberally. The arrow shows where the joint is. The taped section here is about 10cm long.



Figures C, D and E: This is one way to tape the rail to the desk at an angle. It uses 4 pieces of tape. Two are applied directly to the rod; they are then taped to the desk.

In the Classroom **– it is a good idea to arrive 15 to 20 minutes early**

- Before the lesson has begun, set up the railway as you practiced before.

Activity Instructions

Instructions

1. After delivering the activity PowerPoint slides 12-14, divide students into groups of 2-3
2. Give each group their designated materials
3. Initiate Planning Phase
4. Initiate Building Phase
5. Initiate Testing Phase
6. Facilitate Group Rail Run
7. Facilitate Discussion

Requirements and Restrictions

These are also noted on the student handout. They are meant to encourage students to apply the STEM principles they've learned.

1. **Students must build a train car that meets all specifications.**
   - Width between wheels must match rail width (remind them they have rulers)
   - Hooks should be positioned in middle (front and back) of dowel
   - Train car wheels roll, not slide, down the track.
2. **Train cars must connect (via hooks) to other train cars in front and back.**

Organization

Keep track of time during the activity and closely monitor students' progress to ensure they are moving at an adequate pace

Phase	Time (mins.)
Planning	10
Building	30
Testing	10
Group Run and Discussion	15

Planning Phase
Students begin their engineering design process with paper and pencil, evaluating the materials at hand and delegating work to different people in the group.
Building Phase
Students put their plans into action. It is important to encourage them to test throughout the entire building phase to see how their design is coming along and how it needs to be adjusted.
Testing Phase
Students test run the train car on the rail and make finishing touches to optimize their design.
Group Rail Run
This is going to be one of the most hectic parts of the activity. Ask students to form into larger groups and connect their train cars together; there should be three cars per "train" (more will be unstable). Each group will then be able to test their train on the rail and see how well it navigates. This must be closely facilitated by you in order to ensure that all groups have their hooks applied correctly and that trains will not derail and fall apart.

After the Lesson

Ensure that all pieces of the kits have been returned by completing the check list in each kit.

Activity Tips

Q: What if students are having a LOT of trouble designing?

A: Slide 17 has been included at the end of the PowerPoint with examples if the students seem to be struggling to come up with an idea on how to build the carriage.

Q: What if the student's axles won't spin?

A: There is either too much friction or an obstruction at the junction between the frame and the axles. Walk around and evaluate their designs, suggesting that they use a *circular* shape to wrap *loosely* around the axle.

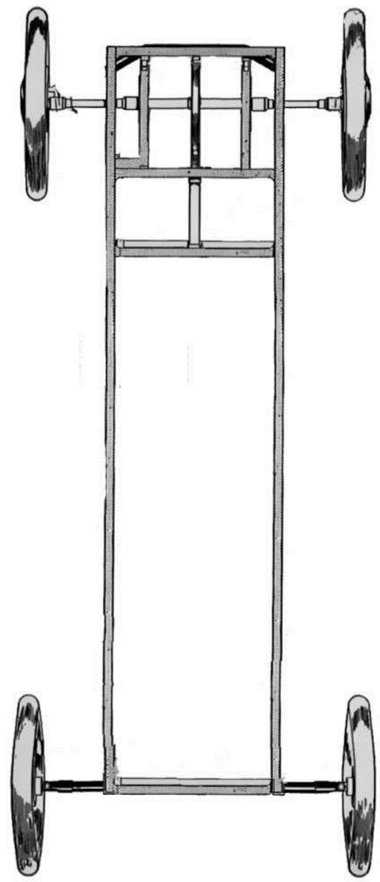
Q: What if the students' designs don't work?

A: Sometimes things go wrong. It's important to show the students what worked in other cases and what didn't work in their case. Try asking during the discussion what they could have done better and what they learned.

Q: What if a student's carriage won't stay on the track?

A: This can be because of a number of reasons. Their carriage may be the incorrect width and not fit on the rail. It could also be because their carriage won't run straight, which happens when the weight isn't evenly distributed or when the frame isn't sturdy enough. In this case, suggest that they make it more rigid so that pieces are firmly held in place (see PowerPoint slide 19).

Train Design



You will need:
Masking Tape
Lollipop Sticks (15)
Dowel (2)
Spool (4)
Scissors
Paper Clips (6)
Wire (6 pieces, 20 cm long)
Ruler

Time: 65 minutes total
10 minutes: Brainstorming and Planning
30 minutes: Building
10 minutes: Testing and Adjusting
15 minutes: Group Run and Discussion

Team
Your team will include 2 to 3 members of your class.

Objective
Design and build a train car:

1. **Build a train car that meets all specifications.**
2. **It has to connect with hooks to your classmates train cars in front and back.**

You will not be given any more materials or any more time.

Specifications
- Width between wheels must match rail width (use your ruler to measure)
- Position hooks in middle (front and back) of dowel
- Your train car wheels have to roll, not slide, down the track

Things to think about for class discussion:
Explain your carriage design. What makes it unique?
Does your carriage work or not? What could make it better?
Did your design turn out how you originally thought it would?

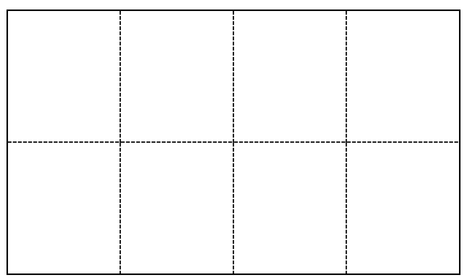
Appendix G: Recommendations for Liaisons

Recommendations for Liaisons

Structure is Key

The key material in this activity is A4 paper, and students will be allowed to repeat testing and building throughout the activity, making it hard to specify how much you will need to prepare. Ideally, have a stack of A4 (At least 10 sheets per group) and five more sheets per group, cut into eighths, creating 40 small segments.

When you find out the size of your audience, you can determine how many kits are needed: 3 to 4 students per kit, and thus how many sheets of paper need to be cut, and how many whole sheets should be prepared. Please cut the segments for the first task in preparation for the activity. The cut sheets should be clean cut eights of A4, cut as shown



Before the lesson, it is suggested you assemble these kits in numbered gallon-sized plastic bags, excluding the paper, which should ideally be in a shared depot. A material list has been provided, Figure X below, as a checklist for you to use before the ambassador picks up the materials. At the end of the activity, the ambassador will then return the kit and the materials included will be marked off. Whether to reuse some or all of these items is up to you, but the activity is designed to reuse almost everything.

Structure is Key Kit Checklist

	Material	**Beginning**	**End**
Per Group	Masking Tape		
	Scissors		
	Ruler		
	Paper		N/A
Whole	Weights		
	Wooden blocks (If Used)		

Train Design

Within our programme package, the Train Design activity requires the most preparation by you and the ambassador to organize materials into kits for student use. We also recommend that two ambassadors run this lesson in a classroom because it will involve many student groups who have to organize during the activity and while testing the train cars.

When you find out the size of your audience, you can determine how many kits are needed: 2 to 3 students per kit. Before the lesson, it is suggested you assemble these kits in numbered gallon-sized plastic bags. A material list has been provided, Figure X below, as a checklist for you to use before the ambassador picks up the materials. At the end of the activity, the ambassador will then return the kit and the materials included will be marked off. Whether to reuse some or all of these items is up to you, but the activity is designed to reuse almost everything.

Train Design Kit Checklist

Material	Beginning	End
Masking Tape		
Lollipop Sticks (15)		
Dowel (2)		
Spool (4)		
Scissors		
Paper Clips (6)		
Wire (6 – around 20 cm each)		
Ruler		

Appendix H: General Presentation and Discussion Tips

Presentation and Discussion Tips

<u>Q: How do I deal with disruptive behaviour in the classroom?</u>

A: One effective way of preventing this is to set ground rules for students when the presentation begins, such as no talking when the ambassador is talking, no talking over others, etc. Making sure that the class as a whole agrees to follow such rules allows you to enforce the rules when they are broken.

Remember that you are not the only responsible adult in the classroom and that there are full time teachers who will help oversee the students. Ask the student for a reason behind the misbehaviour and if there is anything that you can do to help. Offer different seating arrangements, or show them that they are disrespecting the other students.

<u>Q: There are students who dominate the discussion or activity work, while others are too shy to speak out and hardly participate. How do I promote equal participation?</u>

A: Repeatedly emphasize that the most important element of engineering is planning and teamwork. Encourage students to work as a team and come to decisions for the activity after discussion amongst themselves. Allow students to produce responses to questions as a small group, so that students who are too shy to speak out in class are still able to contribute within the team. If a single student is repeatedly answering questions, you can always engage others by saying something like, “I think we haven’t heard from this side of the class yet?”

Q: **<u>There are students who show disinterest in the presentation and the subject material. How should I handle this kind of students?</u>**

A: The first step is to get them involved. Use small prize elements such as chocolates to reward correct answers and participation in questions. This will initially make students focus more on what is being presented, but eventually allow them to find an element that interests them.

Second, remember to address how the subject matter and the engineering challenge is relevant to their day to day lives. Connect real-world examples and applications to the engineering principles instead of presenting them as just another subject.

Third, when providing your professional background, remember to bring up exciting experiences relating to your work, and how math and sciences are a tool you use in work, rather than just a subject you learnt.

Q: **<u>How do I make sure that students will have a positive, educative experience with the programme?</u>**

A: When the activity progresses, ask students to justify their actions and decisions. Utilize the reflection prompting questions that are provided with the Ambassador Presentation and Activity Sheets.

After you explain information, ask simple questions that allow students to review what they have learnt. This way, the key concepts are fresh in their minds as they begin the activity.

Remind students that the activity could easily be replicated or adapted to crafts at home. Encourage students to try different activities at home using materials they have seen being used.

Additionally, if a student makes a good point in a classroom discussion, be sure you give them ownership of that contribution, with prize or recognition. Students will gain confidence and actively participate.

Q: **<u>What are some different ways I can structure the discussion?</u>**

A: There are two main ways you could structure the discussion

One way, called “Snowball” for various opinions and details to collect and be accessible to everyone in the class. Begin by engaging the students with discussion questions in their respective groups. Then, after a certain amount of time, join two or three groups to share their discussions. Finally, bring the discussion to the entire class, allowing individual students to speak out about their group’s approach to the activity, design of the product, etc. and see how each group had different ideas.

Another way to make sure individual students are participating is called the “Marketplace Format.” Allow students to discuss their approach to the challenge provided in the activity in their activity groups. Then, ask the students to form groups consisting of one member from each activity group, and ask them to share what they did to members from different activity groups. This allows individual students to explain the groups design, and promotes each student’s participation in discussing and sharing ideas.

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